IGNITION

By

Carl A. Pfanstiehl

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SECOND EDITION

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and Photographs

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Gift of Mrs. H T Bradley

To the memory of my

Mother

IGNITION

CARL A. PFANSTIEHL

Introductory

Before entering upon the study of electric ignition, it will be well to mention a few facts concerning electricity itself. What is this wonderful agent which can be sent through a small wire many miles long, then made to run our heaviest machinery or to do almost anything from carrying the delicate vibrations of the human voice from one city to another, to the more difficult task of rendering visible to the physician the broken bones of his patient, and last, but by no means least, to enter the cylinders of our engines and ignite the charge at the proper instant? To this, science as yet has no definite answer. However, enough is known regarding its action to enable it to be handled with at least some degree of certainty.

There are two principal forms of electricity: Electricity at rest, known as *"Static Electricity,"* and electricity in motion, or *"Current Electricity."* Matter may be divided into two classes with respect to electricity—insulators through which it cannot pass, and, therefore, must remain where it is placed, and conductors through which it can pass or flow.

Static electricity can be produced by friction; for instance, by rubbing some good insulator, such as a glass or hard rubber rod, with a piece of dry silk or woolen cloth. Its presence on the rod can be shown by the latter's power of attracting small bits of paper, wood, etc. It is easy to show that this electricity is static, by rubbing only a part of

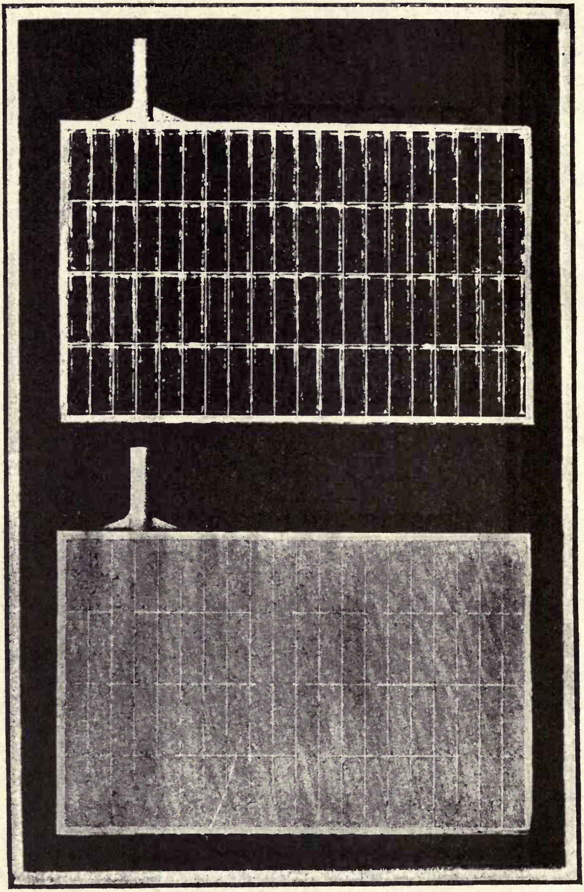
the rod with a cloth and observing that the power of attracting the paper is found only on that part of the rod which is actually rubbed. If a conductor, such as a brass rod, is held in the hand and rubbed with a cloth, it exhibits no such power of attraction. The electricity which is thereby produced, passes from the rod through the body, a conductor, into the earth. It does not remain static on the rod, but passes off as a current. If the conducting rod is provided with an insulating handle and rubbed as before, the electricity so produced will flow to all parts of the rod, and when it has spread over the entire surface, it ceases to flow and becomes static. Thus the entire rod possesses the power of attraction, even though one part only is rubbed. The rod is now said to be charged with static electricity. We will have occasion to refer again to static electricity when discussing the action of the condenser in a jump spark coil.

Our concern here will be mostly with the phenomenon of electricity in motion, or current electricity.

It can be seen from the above that, in order to maintain a current of electricity, it is necessary that the part or circuit, through which it flows, be composed entirely of conductors. If the conducting circuit is broken in any place and an insulator interposed, the flow of current is thereby stopped and it then remains static in the circuit. As a matter of fact, however, it does not remain static very long unless the circuit is unusually well insulated. It leaks out and finds its way to the earth, where it is neutralized.

The force which tends to move electricity must also be present in the circuit if the current is to be maintained. This is called Electro-Motive-Force, abbreviated, E. M. F.

Only the two principal methods for producing the E. M. F. will be considered, viz.: Galvanic and Dynamic. The former is a chemical action, the latter a mechanical one, consisting of a conductor being made to pass across a magnetic field. The former method includes all kinds of batteries—the latter dynamos and magnetos. We will consider first the Galvanic method, later taking up the Dynamic, under the head of "Dynamic Electricity".



Photos showing a cast lead grid, for a storage battery, before and after filling the pockets with the active material.

Foreword

This book was written in response to a growing demand for an explanation of the fundamental principles of ***Electric Ignition.***

The author aims to show the real simplicity of a subject too generally considered obscure, and he believes that the most inexperienced gas engine operator, after carefully reading these pages, will be greatly aided in solving the mysteries of his ignition system.

Chapter Fourteen on low-tension, built-in, gear-driven, make-and-break magnetos will be found especially timely and helpful to the progressive manufacturers of stationary farm engines, many of whom already have adopted as standard equipment this type of ignition in which all batteries and high-speed friction-driven generators are eliminated and the entire ignition system made an integral and permanent part of the engine.

The writer presents with special pleasure the oscillograph tests made by him in his laboratory, which show with absolute accuracy the action of vibrating and make-and-break coils, and the current wave-forms of various magnetos. These original and new experiments enable him to give information that will prove to be of particular interest and value to the student of ignition.

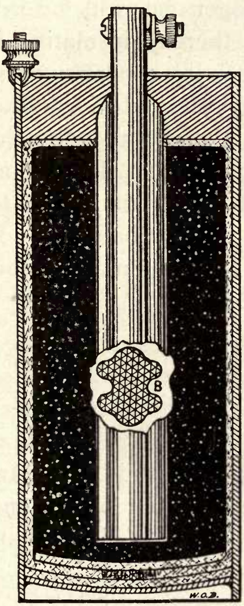
The author wishes to express his thanks to Mr. Oscar Bell, who prepared the drawings.

CONTENTS

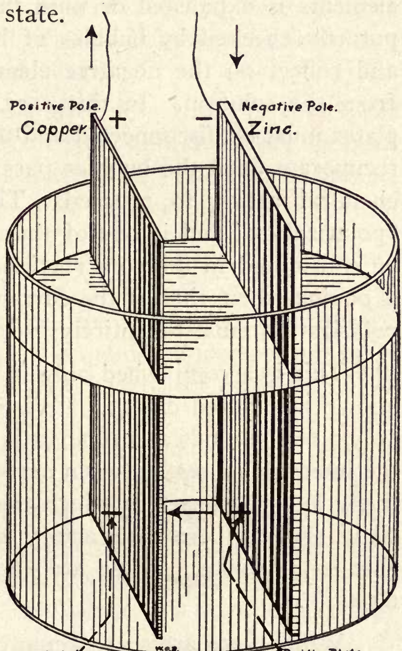
Chapter One

Batteries

Batteries are divided into two general classes, namely, Primary and Secondary. In the former the current is produced by a chemical *decomposition* of the active materials. In the latter by a kind of chemical *change* of the active materials, which change can be reversed, thereby restoring the elements to their original state.



Cross section of ordinary dry cell. Fig. B shows cross section of carbon rod, which has large surface area insuring good contact with the granulated carbon.



Diagrammatic view of a simple galvanic cell.

Primary Batteries.

Primary batteries consist essentially of a chemical solution, called the electrolyte, in which are placed two conductors, one of which will be attacked more rapidly by the solution than the other. During this process the element which is acted upon most, usually receives a negative charge of electricity, and if a wire is connected between the elements, a current flows through it from one to the other. This current continues to flow until either the solution or one of the elements is exhausted or until the chemical action is temporarily checked by bubbles of hydrogen gas which form and collect on the negative element, thereby insulating it from the solution. In this case, the wire connecting the plates must be disconnected and the cell allowed to stand or recuperate until the bubbles pass off, thereby allowing the chemical action to proceed. This process is known as "polarization" and is one of the most important factors to be considered in the construction of primary batteries. It is obvious then, that, if the current is to be maintained, this polarization must be entirely prevented.

This is accomplished only in certain types of batteries, known as "closed circuit." When a current is wanted for only a few seconds at a time, as in ignition apparatus, where the intervals of rest between current impulses are comparatively long, batteries in which the polarization is only partially checked, are satisfactory and somewhat easier and cheaper to make. These are known as "open circuit batteries."

While there are a great many varieties of primary batteries employing different elements and solutions, most of them are more or less unsuitable for ignition purposes,

chiefly for mechanical reasons. The solutions are easily spilled, the glass jars are large and readily broken, and the active elements are more or less expensive and troublesome to renew when exhausted. The internal resistance of these types of batteries is usually quite large, which, as we shall see later, reduces the available current output.

There are, however, two types of liquid cells, known as the Edison Lalande, now called Edison Primary, and the Gordon, which have been found to be a satisfactory source of current in isolated places, where there is plenty of space and no great vibration, and where it is inconvenient to have a storage battery recharged.

It may be well to give a brief description of these cells which are of the closed circuit type, and, therefore, suitable for electric lighting as well as ignition. The active elements are zinc and copper oxide in a solution of caustic potash (potassium or sodium hydrate).

The Edison Primary Cell.

In the Edison Primary cell the copper oxide with some magnesic chloride added to it, is molded under pressure into plates of the proper size and then baked; the magnesic chloride serving to bind the mass together. The black oxide plate thus formed is suspended in a copper frame between two thick plates of zinc. Polarization is done away with in this case, since the hydrogen as fast as it forms, combines with the oxygen of the copper oxide, forming water, thus gradually reducing the oxide to red metallic copper. The amount of black active oxide left in the plate at any time can be ascertained by picking into it with a pen knife. If the plate is red throughout the entire mass, it is exhausted and requires renewal. If, however, there is a layer of black

in the interior, there is some life left, the amount depending upon the thickness of the layer of black oxide still remaining.

It is very important that a layer of heavy paraffine oil about ¼ inch thick be kept floating on the surface of the solution to prevent corrosion and to protect it from a deteriorating chemical action with the air. If this is not done, the life of the battery will be reduced over one-half. It is also necessary to have the oxide plate kept one inch below the surface of the solution. This cell gives an E. M. F. of 0.7 volts and can furnish a current continuously during its life of from two to seven amperes, depending, of course, upon the size of the active elements. These cells range in size from 150 to 600 ampere-hour capacity.

The Gordon Cell.

In the Gordon type of cell, the oxide is powdered or flaked and contained in a perforated sheet iron can. The zinc takes the form of a cylinder placed around the oxide can and held in place by porcelain lugs. The containing jars are either porcelain or enameled steel, and with the latter, a tight fitting compressed fiber cover is used, which is practically liquid tight, thus making the cell suitable for portable engine and marine work. It is extremely easy to renew the exhausted elements of this cell, as the loosening of one screw will permit the exchange of both the oxide can and the remains of the zinc for fresh elements. A layer of paraffine oil must be kept on the surface of the solution as in the Edison Primary cell. Both the Edison and the Gordon batteries have the advantage of never freezing and while severe cold slightly reduces their efficiency, it by no means

prevents their satisfactory action. Gordon cells have worked satisfactorily at a temperature of 15 to 20 degrees below zero.

The Dry Cell.

The most popular primary battery is the well known dry cell.

The active elements of the dry cell are zinc and carbon in an electrolyte, consisting principally of ammonium muriate. The containing can is made of sheet zinc, which also forms an efficient positive element, as the active surface is large. The inside of the zinc can is lined with some absorbent material such as blotting paper, and to prevent internal short circuit great care must be exercised that no cracks or holes are left to allow the zinc to come into direct contact with the carbon. A rod of solid carbon carrying a binding post, is placed in the center and the space around it is filled with a solidly packed mass of granular carbon, forming a negative element. With this carbon is mixed some manganese dioxide as a depolarizer. The fibrous lining is saturated with a solution consisting principally of ammonium muriate, which forms the electrolyte. The cell is then hermetically sealed with some kind of sealing wax. In this way the elements present large active surfaces without unduly increasing the size of the cell.

When the cell is put to work, it starts to polarize; that is, hydrogen gas is formed in quantities depending principally upon the *rate* at which the cell is discharged, and, unless the gas is absorbed in some way, it will not only interfere with the chemical action, but will cause the cell to swell or puff out, sometimes even bursting it. If the hydrogen is not formed too rapidly, however, it is disposed of by com-

bining with the oxygen of the manganese dioxide which was mixed with the carbon. If the cell is discharged at a rate high enough to cause hydrogen to be produced more rapidly than the manganese dioxide can absorb it, the cell will soon be ruined unless it is given frequent intervals of rest long enough to allow the gas to be absorbed. This is how a cell recuperates. If, on the other hand, the rate of discharge is kept so low that the gas will be absorbed as fast as it is produced, the cell will not need to recuperate as much and can be used on closed circuits such as electric lighting. The closed circuit discharge limit for most good dry cells is about one-quarter ampere and better results are obtained with even less. This is why the life or efficiency of a dry cell is so dependent upon the rate of discharge. The greater the discharge rate, the longer and more frequent must be the intervals of rest, and the less will be the total efficiency. This will be considered later more in detail when the methods of caring for and connecting cells are described.

The success of a dry cell depends not only upon the selection and purity of the elements used but upon the manner and uniformity with which they are handled during the process of manufacture. For instance, an impurity on the inside surface of the zinc will usually be all that is needed to constitute a tiny local cell, which causes a current to flow from the impurity to the zinc and back again through the electrolyte. This will continue until the speck of foreign matter is set free by the surrounding zinc being eaten away or until the electrolyte around it is exhausted. This process is known as "local action" and, fortunately, in the better grades of dry cells is practically prevented. A careful manufacturer of dry cells uses machinery largely in the

work, thus eliminating the variable personal factor, and several tests for voltage and amperage are made during the process of construction. The cells are then allowed to season for four days and after a final test are packed for shipment.

Secondary or Storage Batteries.

A brief mention only can be made of the principle of the secondary or storage battery. In this cell, as stated before, the current is the result of a chemical change, which takes place within the cell. This change differs from that in the primary cell, in that, when the active elements are exhausted, it is not necessary to replace them with new ones, but the old ones can be re-formed or reconstructed, as it were, by passing a current of electricity from some outside source, through the cell. The direction of the charging current is, of course, opposite to that during discharge. A storage battery, then, is not, as most people believe, a reservoir, into which electricity can be pumped and held for a time then drawn off as desired. What is actually stored in the cell is not electricity, but chemical energy in a potential state. With this fact clearly fixed in mind, the operation and care of storage batteries becomes a comparatively simple matter.

While there are several kinds of materials, which can be employed, the combination most universally used is that of lead plates in an electrolyte of dilute sulphuric acid. The active material on the positive plate is peroxide of lead ($Pb\ O_2$), and on the negative, spongy lead (Pb). The plates usually consist of a cast lead framework or grid, having many pockets, which are filled with the active material. Several of both kinds of plates, always one more negative

than positive, are alternately assembled together, but insulated one from another by thin strips of rubber or wood, the positive and negative plates being respectively connected to the positive and negative terminals of the cell. In the ignition type of batteries there are usually three positive and four negative plates, the capacity of the cell depending upon the total area of the plates. The containing jars are glass or hard rubber and the electrolyte is a ten per cent solution of sulphuric acid in distilled water. A good storage battery will last for several years if properly cared for, but it must be guarded against several diseases to which it is susceptible.

Edison Storage Battery.

How about the new Edison storage battery upon which the great inventor has been experimenting the last eight years at an enormous expense? It is undoubtedly a success, and, were it not for the excessively high cost of production, would soon replace the lead cell, being free from the list of diseases which beset the lead battery. The active elements are oxides of nickel and iron in an electrolyte of potassium hydrate (KOH).

The grids are made of nickel-plated pressed steel, the positive containing nickel oxide mixed with flaked metallic nickel, the latter material reducing the resistance of the oxide. The negative grid contains iron oxide, commonly known as iron rust, and the containing cans are made of nickel-plated steel, having all seams welded. This cell will stand a great deal of abuse.

Chapter Two

Electrical Units and Laws Governing the Flow of Electricity

In the preceding chapter a few general principles of electricity were discussed. Consider now a few laws which govern its rate of flow, and learn how an understanding of these laws can aid us in the proper installation and care of batteries. We have seen that there are two conditions that must be fulfilled before a current of electricity can be produced, namely, a complete circuit, composed wholly of conductors, and included as a part of that circuit, some source—or sources—of Electro-Motive-Force.

Volt.

The unit of E. M. F. is called the Volt, and represents a certain specific amount of *that force which tends to move electricity.* The volt, therefore, signifies electrical pressure only, and does not designate any particular quantity of electricity.

Ampere.

The unit of volume or size of an electric current is called the Ampere and represents a certain specific *rate of flow.* The ampere, therefore, signifies *volume of current* only, and *not* any particular quantity of electricity. Volts correspond to pounds pressure in a water pipe, and amperes to the size or volume of the stream.

Ampere Hour.

In order to measure any particular quantity of current electricity, we must introduce the factor of time. Static electricity can be stored, that is, held for a while in *condensers,* and its quantity then measured; but not so with current electricity. If a fixed number of amperes flows past a given point in a wire for a definite period of time, a certain specific quantity of electricity will have passed that point. The unit quantity of electricity is determined when *one ampere flows for one second,* and is called a *coulomb.* As the coulomb is a very small unit, it has been replaced, in practical work, by the ampere-hour, which is one ampere flowing for one hour, or the equivalent. One ampere-hour, then, equals 3,600 coulombs.

We have already pointed out that electricity can only pass through certain substances known as conductors and not through others called insulators. Further experimenting would have disclosed the fact that there is no such thing as a perfect conductor* or perfect insulator, and that the power of conducting electricity by different materials greatly varies. Silver is the best known conductor, but even it offers some opposition to an electric current. Therefore, when a current is forced through a conductor, the attending "friction" produces heat, and, if sufficient current is used, the conductor can actually be melted.

Ohm.

Since a current encounters *resistance* in its passage through a conductor, it is easy to see that a given E. M. F.

*An Electron—the absolute unit of electricity—may be a perfect conductor within itself. For an interesting and authoritative treatise on this and similar subjects, see "Electrons," by Sir Oliver Lodge, D. Sc., F. R. S., and also "Electricity and Matter," by Sir J. J. Thomson, D. Sc., F. R. S.

is capable of forcing a given current through only a certain definite resistance. The logical unit of resistance, therefore, is *that amount of resistance through which a pressure of one volt can force a current of one ampere,* and is called the Ohm.

Watt.

One other unit must be mentioned, namely, that of electrical energy or power. It is easy to see that a certain current, propelled by a high E. M. F., represents more power than the same current propelled by a low E. M. F. The unit of electrical power, therefore, is *that amount of power exerted when one ampere flows under a pressure of one volt,* and is called a Watt. It follows that a watt is a volt-ampere, and that *the power in watts exerted in a direct current circuit is equal to the total number of volts multiplied by the amperes, acting in that circuit.* The readings of voltage and amperage must, of course, be taken simultaneously. This relation can be expressed algebraically thus:

$$W = I\,E \qquad (1)$$

where W stands for watts, I for amperes, and E for volts.

Having clearly fixed in mind the meaning and values of these various units, their numerical relations can be discussed.

Ohm's Law.

Many years ago, Dr. Ohm, after whom the unit of resistance was named, discovered that, in a circuit of constant resistance the current *increases* as the voltage is *increased;* and with a constant E. M. F. the current *decreases* as the resistance is *increased.* This fact is known as "Ohm's Law" and is the fundamental law of electricity, since it

governs the rate of current flow in direct current circuits. Its importance, therefore, cannot easily be over-estimated. Ohm's Law may be stated as follows:

The current in a direct current circuit varies directly as the total E. M. F. and inversely as the total resistance acting in that circuit;

or:

$$\text{Strength of current in amperes} = \frac{\text{E. M. F. in volts}}{\text{resistance in Ohms}}$$

and expressed algebraically:

$$I = \frac{E}{R} \quad \text{(2)}$$

where R stands for Ohms. By simple transposition we have:

$$R = \frac{E}{I} \quad \text{(3)}$$

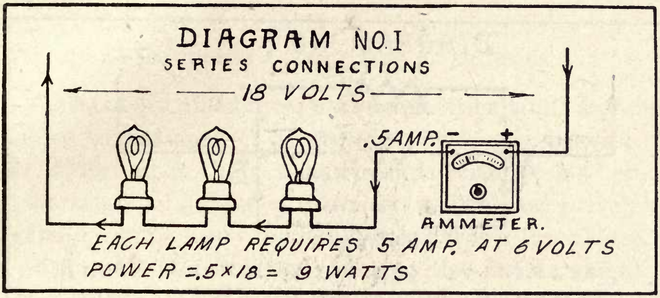
and

$$E = I\,R \quad \text{(4)}$$

It is evident that if two of the factors are known, the third can easily be calculated.

Series Connections.

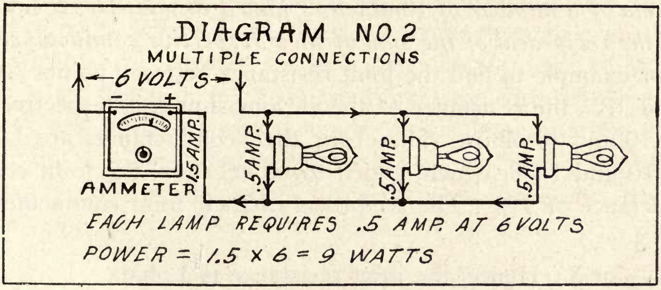
A word now about series and parallel circuits before we take up the practical application of these principles. If we join a number of conductors together, end to end, in a circuit, so that the entire current will have to pass through each one successively, they are said to be connected in series,



and it is obvious that the total resistance will be the sum of their respective resistances. Series connections are illustrated in diagram No. 1.

PARALLEL CONNECTIONS.

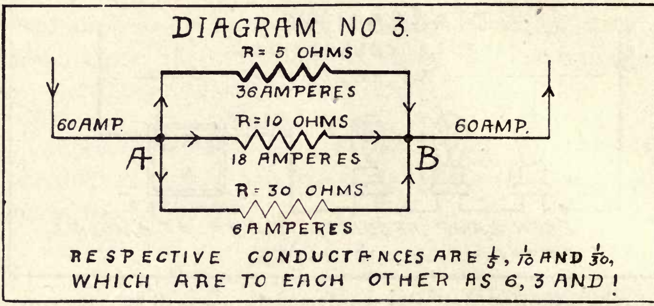
If, on the other hand, we connect several conductors together, so as to provide a number of separate paths through which the current can flow from one point to



another, they are said to be joined in parallel or multiple; and each separate conductor is known as a Shunt on the others. Multiple connections are shown in diagram No. 2.

JOINT RESISTANCE.

To figure the joint resistance of several conductors, connected in multiple, as between points "A" and "B" in dia-



gram No. 3, first find the joint conductance by adding the respective conductances of the various branches; the word "conductance" meaning the precise opposite of resistance, and equal numerically to the reciprocal of the resistance in ohms. The joint resistance, of course, is the reciprocal of the joint conductance. Therefore, *the joint resistance in ohms of a number of conductors joined in multiple, is equal to the reciprocal of the sum of their respective conductances.* For example to find the joint resistance between points "A" and "B", the resistance of the various shunts is respectively 5, 10 and 30 ohms. Therefore, their conductances are 1/5, 1/10 and 1/30, which, added together, equal the joint conductance of 1/3. The reciprocal of their joint conductance is $\frac{3}{1}$ or 3. Hence, the joint resistance is 3 ohms.

Current in Branch Circuits.

Referring again to diagram No. 3; notice that the current flowing from the battery divides when it reaches point "A" and part of it flows through each branch, the current, of course, dividing in direct proportion to the conduct-

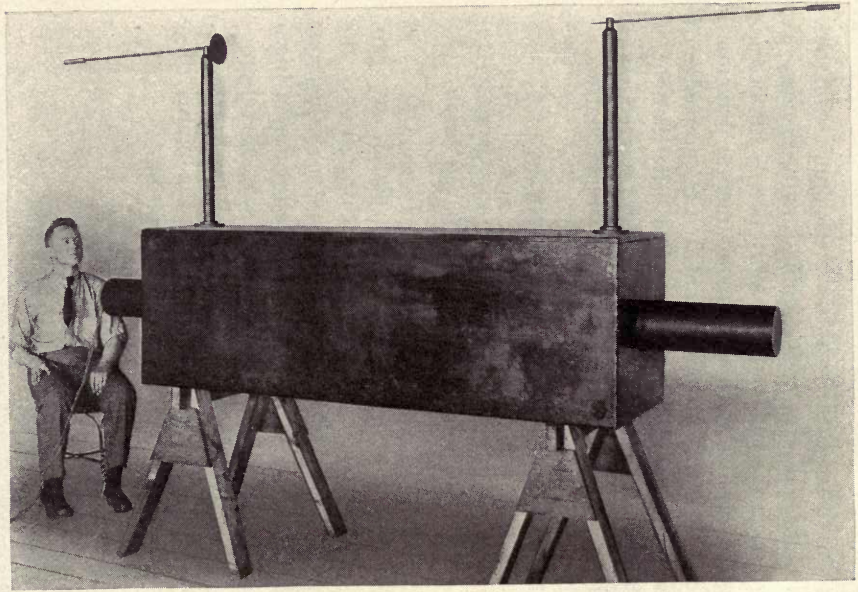
ances of the several branches. This principle is used to advantage in the multiple connecting of batteries.

We have discussed these various electrical units and their relations to one another at considerable length, because we wish to urge upon the reader the importance of his becoming thoroughly familiar with these fundamental principles, especially Ohm's Law, for he will find that a knowledge of the basic principles involved, along with a little thought, is all that is needed to make the locating and correcting of faults in his electrical equipment a very simple matter.

Resistance of Different Materials.

The table herewith, shows the approximate resistance of different materials, as compared with that of pure copper, which is taken as "I".

Since there is no known perfect insulator, we can, according to Ohm's Law, force a current through even the best insulator, provided we *sufficiently increase the voltage,* but, when this is done, the current takes the form of a jump spark and burns its way through the insulator, thereby destroying it. This phenomenon is known as "disruptive discharge" and is what takes place between the points of a spark plug in the jump spark system of ignition.



The largest induction coil of its kind in existence. It has 250 miles of wire in the secondary and the core is 9 feet long. The insulation between the primary and secondary is a built up mica tube ¾ of an inch thick, 9 feet long and weighs 90 pounds. It throws a flaming spark over five feet long. Mr. Pfanstiehl built this monster coil to prove his patented system of pancake winding and uses it in his Laboratory for experimental work.

TABLE OF COMPARATIVE RESISTANCES.

(MATTHIESSEN'S STANDARD.)

COPPER = 1.

MATERIALS.	RELATIVE RESISTANCE.	
Silver annealed	0.925	GOOD CONDUCTORS
Copper	1.00	
Gold (99% pure)	1.38	
Aluminum (99% pure)	1.61	
Zinc	3.62	FAIR CONDUCTORS
Platinum, annealed	5.65	
Iron	5.70	
Nickel	7.78	
Tin	8.28	
Lead	12.8	
Antimony	22.1	
Mercury	59.3	
Bismuth	82.2	
Carbon (arc light)	2510.0	
Sea water		POOR CONDUCTORS
Ordinary water		
Dampness		
Damp wood		
Partly carbonized oil		
Dirt of any kind, etc		
Leather, cured		POOR INSULATORS FOR VOLTAGES HIGHER THAN 1,000 BUT FAIRLY GOOD FOR LESS VOLTAGE
Ordinary dry wood		
Black vulcanized or hard fibre		
Red fibre		
White vulcanized or hard fibre		GOOD INSULATORS
Ditto—Boiled in paraffine		
Kiln dried wood		
Ditto—Boiled in paraffine		
"Electros" or composition materials		
Asbestos (dry)		
Various dry oils		
"Empire" oiled fabrics		
Card board and paper boiled in paraffine		
Shellac (dry)		
Insulating varnishes		
Micanite cloth and paper		
Rubber (soft)		
Rubber (hard)		
Porcelain		
Paraffine, beeswax, rosin, etc		
Sulphur		
Glass		
Mica		

Chapter Three

Connecting, Testing and Care of Batteries

Consider now the purely practical side of the subject. Suppose one wants to buy some dry batteries. He should not accept any cell the clerk in the store gives him. He ought first to ask for some well-known make. Then look at the date stamped on the cell, and, if it is several months old, the chances are ten to one that the small amount of moisture or electrolyte originally in the cell is already half dried up.

Testing Dry Cells.

After finding a cell, bearing a recent date, test it for amperage with a pocket "battery tester" or ammeter, which should have been previously compared with a larger instrument for accuracy. Hold the ammeter in contact only the fewest possible seconds necessary to obtain a reading, for, since the resistance of the ammeter is extremely low—in fact practically nothing—the cell while being tested is discharging at its maximum possible rate.

The cell showing the highest amperage is not necessarily the best. This reading is *not* an indication of the amount of electricity in the cell, but, rather of the highest possible rate of chemical action that the active elements and the depolarizer can undergo. By the use of extra strong

chemicals in the construction, a standard No. 6 cell can be made to show 40 amperes or more, but, when this is done, the chemicals will soon burn themselves out, without doing useful work, and greatly reduce the life of the cell. It has been found that the combination of chemicals best suited for long life and efficiency, under ordinary conditions, in the standard No. 6 cell, is that which will cause the latter to test 16 to 20 amperes. However, this may vary slightly with different good makes of cells. As severe cold temporarily checks chemical action, dry cells will not show their full strength when chilled through; and, on the other hand, cells should not be kept too warm, as their chemical action would be unduly stimulated, thereby shortening their life.

Should we be without an ammeter, a rough test can be made by holding a nail or a key firmly against the zinc binding post, screwed up tight, and touching the surface of the carbon rod with the smallest point possible. Owing to the high contact resistance of carbon, if the cell is quite new, a tiny red spark or arc, accompanied by a little puff of smoke, will form at the point of contact; if, however, just a little black ring forms on the carbon around the point of contact, there is some life left, sufficient usually to run the engine a few hours at least. With a little experience, a fairly accurate test can be made in this way. If a cell in a set will not pass this test, or show 4 or 5 amperes on an ammeter, it is dead and should be thrown out, as it adds to the resistance of the circuit, and thereby tends to check the current flow from the rest of the cells.

E. M. F. of Cells.

The E. M. F. of a primary cell depends upon the character of the active elements, and not upon the size of the cell.

Dry cells, regardless of size, should, when new, show about 1.5 volts, which figure, however, is rarely ever reduced even to 1.2 when the cell is exhausted, provided the reading is taken on "open circuit," viz.: when there is no current being drawn from the cell. The voltage of an exhausted cell will, however, drop to nearly nothing the instant an attempt is made to draw a current from it. An ammeter, however, is much to be preferred in ascertaining the condition of dry cells.

Amperage of Cells.

The amperage, which can be drawn from a cell, increases directly with the size or rather the area of the active elements. Should we find ourselves dependent for a few hours run upon a newly exhausted set of dry cells, we can coax them into action for a while longer by breaking out the sealing wax on the top and pouring in as much water as will be absorbed, as this tends to reduce the internal resistance. The internal resistance of a No. 6 dry cell, when new, is about 0.064 ohm.

In setting up wet or liquid cells, follow the directions given by the maker, being careful not to get any dirt into the electrolyte.

Testing Storage Batteries.

An ammeter should never be used to test a storage battery, for, owing to the extremely low internal resistance of both, a current of 100 or 200 amperes would flow, which would not only wreck the ammeter, but ruin the plates of the cells as well. A low reading voltmeter should be used to test storage batteries, and should show two volts per cell when pretty well charged, and when the voltage per cell drops to about 1.8, it should be recharged. The voltage

should never be allowed to drop below 1.7. These readings should be taken when the battery is discharging under normal conditions. A lead storage battery should not remain long in an uncharged condition, as lead sulphate ($Pb\ SO_4$) will form on the plates. As this material has a high resistance, it tends to insulate the plates from the electrolyte, thereby greatly increasing the internal resistance of the battery, which, of course, reduces the available current. This process is known as "sulphation," and is the most common disease of the lead battery. The remedy for a mild case of sulphation is a very long charge at about one-fourth or less of the normal charging rate.

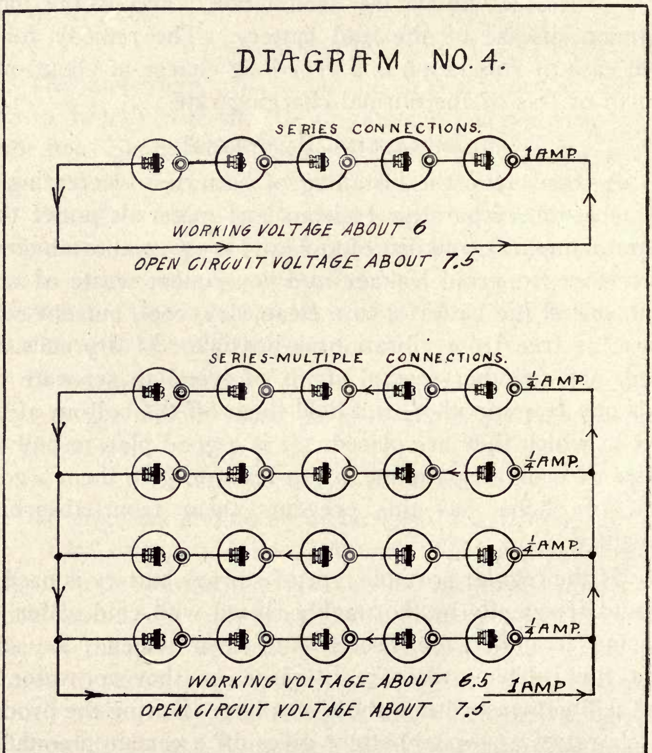
Installing Batteries.

A word upon the installing of batteries. Referring to the table of comparative resistance of materials notice that water, dampness, and dirt of any kind are partial conductors. Therefore, to avoid leakage and consequent waste of current, install the batteries in a clean, dry, cool, but not cold, place, as free from vibration as possible. If dry cells are used, nail together several strips of wood to separate the cells one from another, and hold them off the bottom of the box in which they are placed. It is a good plan to boil the strips of wood in paraffine, or, at least, to give them a good coat of shellac, as this prevents them from absorbing moisture.

If the regular portable type of storage battery is used, it should frequently be thoroughly rinsed with cold water, by placing it under the faucet, and then wiped. Be sure that the rubber corks are in place, so that no water or dirt will get washed into the electrolyte. During the process of charging, a storage battery gives off a certain amount of

acid spray, which, if allowed to remain, rapidly corrodes the terminals and destroys the wooden case. No trouble need be experienced from the acid, if the battery is thoroughly washed after each charge, or oftener. Cleanliness is the main thing to observe in the care of batteries.

In connecting cells together, flexible conductors should be used, or better yet, the little copper battery connectors that are made for the purpose. Be sure to see that the bind-



ing nuts are tight, and particularly that the screw attached to the carbon rod in a dry cell is very tight, so as to reduce the contact resistance of the carbon to a minimum.

A loose contact with the carbon rod is a fault often very troublesome to locate, for it does not completely shut off the current, as does a broken wire, but, owing to the high resistance, permits only a part of the current to flow.

When several cells are joined together, to form a single source of E. M. F., the whole is called a battery. It is well to use cells of the same make and necessary that they be of the same age and in the same condition. It is not economy to connect a new cell with several old ones.

Voltage and Amperage of Set of Cells.

When cells are connected in series, and the entire current thereby made to flow through each one successively, it is easy to see that no more current or amperage can economically be drawn from the set than from one cell. The E. M. F., however, will be increased as the current proceeds from one cell to the next; therefore, *the total voltage of a number of cells connected in series is equal to the sum of the voltage of the separate cells and the total amperage is no greater than that of one cell.*

It is important that we learn the voltage best suited economically to operate our electrical apparatus; this information can best be had from the manufacturers. While most ignition apparatus is designed for use with six volts, there is some apparatus which requires eight, and others work more satisfactorily and efficiently on four. Taking 1.5 volts per dry cell, we see that four cells in series will give an E. M. F. of six volts, but, because the internal resistance

of dry cells increases as the cells are used, reducing the available or working E. M. F., five cells instead of four, are usually used for six-volt apparatus.

Since the life of a dry cell depends almost entirely upon the rate of discharge, it is desirable to keep the current flowing through the cells, as low as practicable. By connecting a number of batteries, of equal voltage, in multiple, the current divides, as we have seen, and only a part flows through each branch, thereby reducing the demand on each battery.

Current from Cells in Multiple.

The number of amperes flowing in a circuit governs the number of sets of cells to be connected in multiple. A low reading ammeter should be included in the main circuit to show the amperage, and a sufficient number of batteries should be placed in multiple to reduce the current in each branch to ¼ ampere, or less, if they are to work on closed circuit, as in operating electric lights. This is illustrated in diagram No. 4.

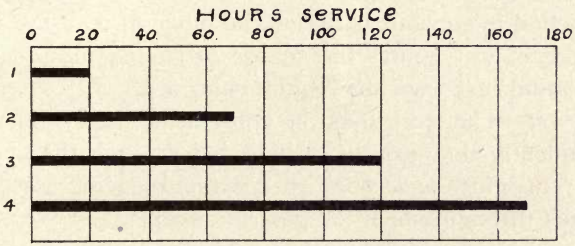
The demand for current made by a single-cylinder engine, if an efficient coil is used, is not too great to be efficiently furnished by one set of cells in series. For operating multiple cylinder engines, much more efficiency is to be had from ten cells, connected in series-multiple, than if they were used in two separate sets of five in series. It would be well to have as many sets in multiple as there are cylinders, but this is often impracticable.

The results of many careful tests, made to show the increase in efficiency of dry cells, when connected in series-multiple, are given below. Tests were made on a four-cylinder automobile engine, in severe service, as well as in many other ways.

Tests of Cells in Multiple.

When dry cells are connected in series-multiple, four in series will usually have sufficient working voltage to operate six-volt apparatus, since the internal resistance of a battery, composed of cells in series-multiple, is much less than in one

RESULTS OF PRACTICAL TEST ON DRY CELLS.



NO.	ARRANGEMENT OF DRY CELLS.
I	1 SET OF 4 IN SERIES.
2	2 SETS OF 4 IN SERIES-MULTIPLE.
3	3 SETS OF 4 IN SERIES-MULTIPLE.
4	4 SETS OF 4 IN SERIES-MULTIPLE.

set of cells in series. For some apparatus, however, particularly electric lights on closed circuit, it is well to have the battery composed of sets of five cells in series, which will insure an average working E. M. F. of about six volts.

Chapter Four

The Simplest Form of Electric Ignition

Having a fairly good idea of an electric current, its production in galvanic batteries and mode of travel, we shall now see how it ignites the charge in gas engines. Clearly fix in mind just what the requirements are.

First—The work must be done inside the cylinder, and consequently the current must be led through the cylinder walls; this must be accomplished without leaving any cracks or leaks through which the gas can escape.

Second—Enough heat must be developed to instantly ignite the charge under all conditions.

Third—The ignition must occur at a certain fixed time, without a variation of so much as a hundredth or even a thousandth part of a second.

Fourth—The apparatus must be very reliable and therefore simple.

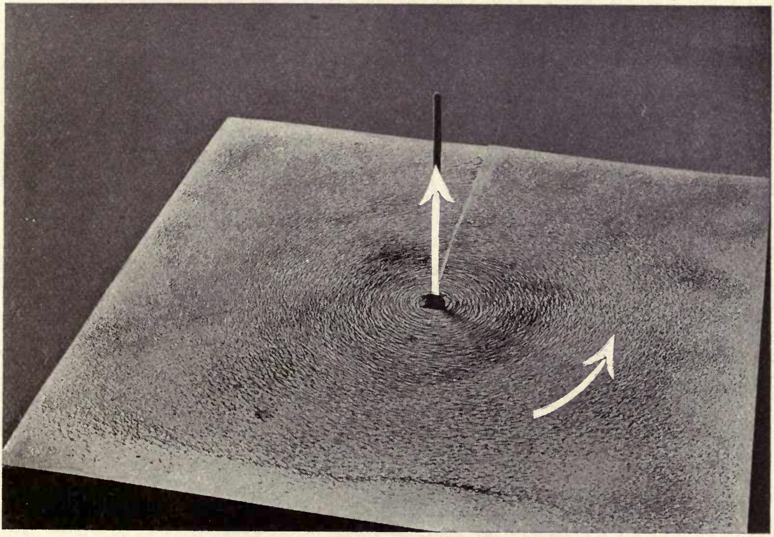
Fifth—It must be efficient.

Electric ignition may be divided into two general classes—the Jump Spark or High Tension, and the Touch Spark or Low Tension systems. We will confine ourselves in this chapter to the Touch Spark system.

Make and Break Ignition.

There are three principal parts to Touch Spark ignition, namely, a source of E. M. F., a Touch Spark or Primary coil, and an Igniter.

The source of E. M. F. may be any suitable galvanic battery of usually four to six volts, such as a set of four or



Photograph showing magnetic field, generated around a copper wire carrying a current of 120 amperes. The wire passes through a piece of paper and the magnetic lines are formed by iron filings sprinkled on the paper.

five dry cells; or a low tension Dynamo or Magneto. In some special forms of magnetos, the primary coil is combined with the armature of the machine itself. This latter system will be described in detail in the last chapter.

Before the action of the Touch Spark coil can be understood, mention must be made of a most important characteristic of current electricity.

An electric current does not confine its influence solely to the conductor through which it passes, but sets up a kind of rotary disturbance, in the nature of whirls, at right angles

Series of diagrams showing various steps in increasing the magnetic field surrounding a current carrying wire. With a properly constructed coil as in Diagram 4 the apparent momentum of the current can be increased many times, which results in a hot spark when the circuit is broken.

Diagram No. 1
Shows the beginning of the magnetic lines forming around the wire instantly after the circuit is closed.

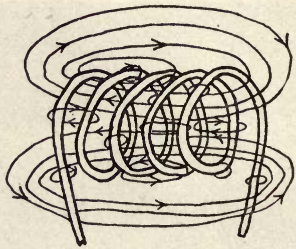


Diagram No. 2
Shows how the magnetic lines combine an instant later.

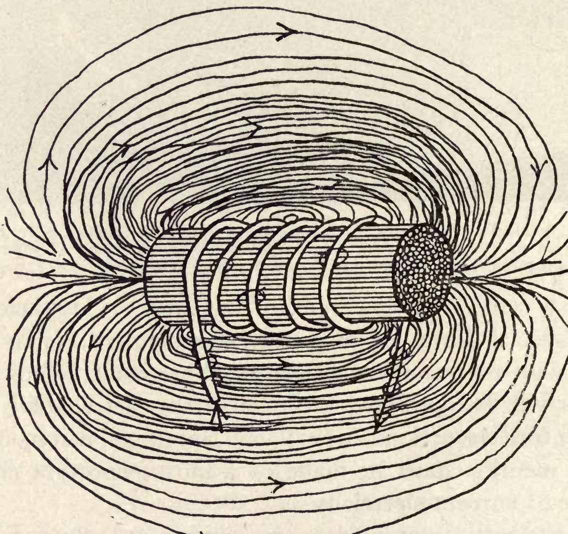


Diagram No. 3
Shows how the magnetic density is increased by placing a piece of iron in the center of the coil.

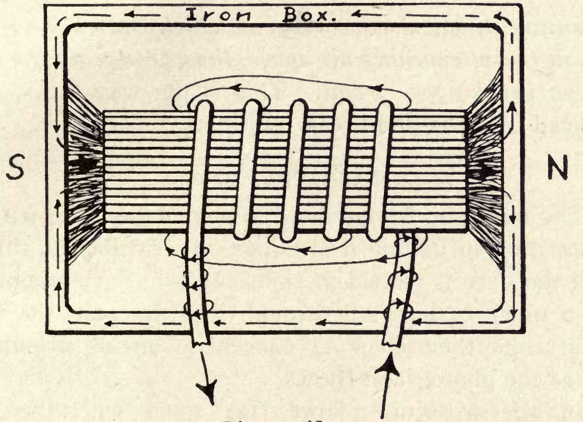


Diagram No. 4
Shows how the magnetic density is still further increased by placing the coil in an iron box.

to and around the wire, in the all-pervading Ether-of-Space.[1] This phenomenon is the same as that near the poles of an ordinary magnet and is known as Magnetism; in other words, an electric current magnetizes the space around it.

ELECTRIC INERTIA AND MOMENTUM.

When a circuit is completed, the current starts to flow, but is held back for an instant by its growing magnetic field, and consequently does not reach its full value, as determined by Ohm's Law, until its magnetic field has ceased to grow and become constant; and, conversely, a current does not instantly stop on breaking a circuit, but is maintained for a moment by the collapsing or shrinking of the magnetic lines. An electric current, therefore, appears to possess *inertia* and *momentum,*[2] and it is *this tendency to persist or apparent*

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[1] See an article by the author in POWER BOATING for July and August, 1910.

[2] (For an interesting and non-mathematical treatise on Electricity and Magnetism, see "Modern Views of Electricity," by Sir Oliver Lodge, F. R. S. This book is obtainable through The Penton Publishing Co., Cleveland, O.)

momentum of an electric current which causes it to burst through the intervening air space, thus producing the spark seen on breaking a circuit. This is the way the spark is produced in make-and-break ignition.

Magnetic Field.

The magnetic field around a current-carrying wire can be shown by sprinkling iron filings on a cardboard, through which the wire is passed at right angles. Since magnetism finds a much easier path through iron than air, the filings will arrange themselves in concentric circles around the wire, as the photograph shows.

In order to secure a large, "fat" spark, when the circuit is broken, the apparent momentum of the current must be increased, which can be done by increasing the surrounding magnetic field. This, in turn, can be accomplished by winding the wire into a compact coil, making the current circulate around a small space many times, thereby greatly concentrating the magnetism. In this case the magnetic lines around each turn of wire tend to open up and include the other turns. The magnetic density can still further be increased by placing a piece of iron in the center of the coil. With a properly constructed coil of this kind, the apparent momentum of a current can be increased many times, resulting in a fat, hot spark when the circuit is broken.

The Igniter.

The igniter is simply a means for making and breaking an electric circuit inside the cylinder, and usually consists of two electrodes, insulated from each other, one fixed in position and the other moveable into and out of contact with it. Usually a lever, extending from some moving part

of the engine, engages the moveable electrode, causing a separation at the instant ignition is required.

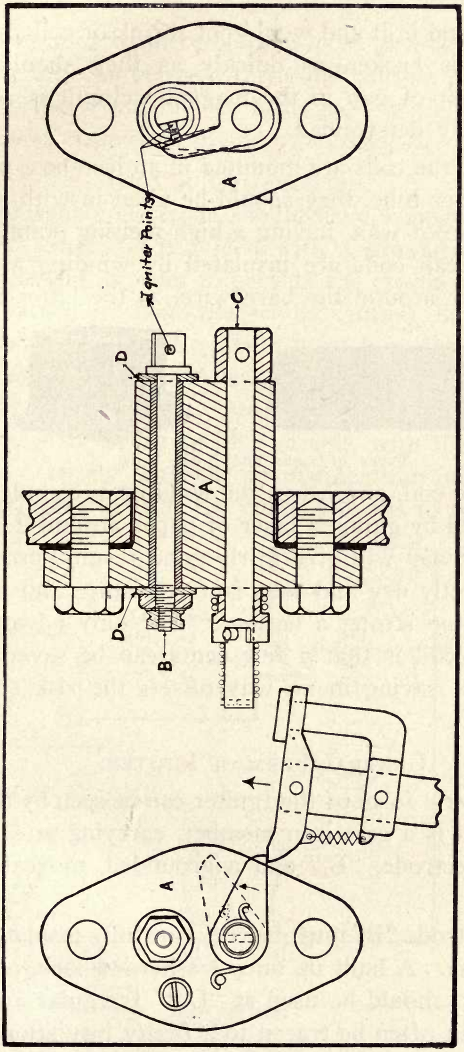
Having now a general idea of the theory of make-and-break ignition, we will in the next chapter turn our attention to the practical construction and operation of its parts.

Chapter Fvie

Construction and Operation of Make-and-Break Coils

The Make-and-Break coil consists of a few hundred turns of insulated copper wire, varying in size from No. 14 to 20 B. & S. gage, wound around an iron core, about an inch in diameter, and from 3 to 10 inches long. Since magnetism does not penetrate to the center of and saturate a thick bar of iron as readily as a thin one, the core is made up of a bundle of small iron wires. If the best results are to be obtained, the iron wires must be thoroughly annealed, to make them as soft as possible, otherwise the magnetic lines cannot easily rise and fall through them. The turns of copper wire must be well insulated one from another, to prevent leakage or short-circuits.

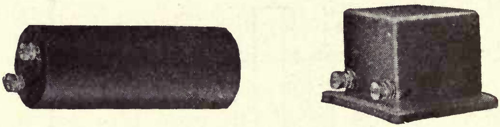
Some kinds of Make-and-Break coils are placed in an iron box, which provides a nearly complete circuit of iron, through which the magnetic lines can pass. This tends to increase the time required for the magnetic field, and consequently the current, to build up to its maximum. In this construction, however, a small space should be left between the ends of the core of the coil and the iron box, in order to make the magnetic lines jump a small air gap, for, if the magnetic circuit were composed entirely of iron, the path would be so good that the magnetic lines would keep on



Drawing showing details of the general form of make and break igniter.

spinning around in it and would not shrink or collapse when the current is broken as quickly as they should. The proper amount of gap in the magnetic circuit is a matter to be carefully determined.

Whether the coils are mounted in an iron box, paper or vulcanized fiber tube, they should be filled in with an insulating waterproof wax, having a high-melting point. Some Make-and-Break coils are insulated by winding a narrow strip of paper around the bare wire, as the latter is being



Types of make and break coils.

wound on the coil, and, when the winding is completed, the coil is finished by gluing a layer of paper around it. A coil made in this way will give fairly good results, provided it is kept perfectly dry and free from moisture and not connected with too strong a battery. The only advantage in this kind of coil is that a few cents can be saved on the cost; but this saving in no way offsets the risk sustained by its use.

General Form of Igniter.

The general form of the Igniter can be seen by the illustration. "A" is a cast iron member, carrying an insulated stationary electrode, "B," and a grounded, moveable electrode "C."

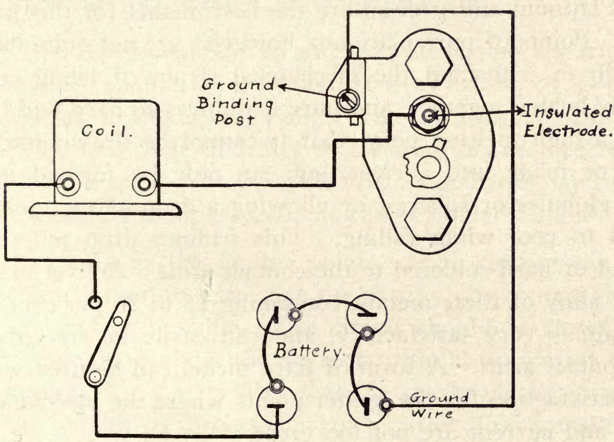
The electrode "B" must be very carefully insulated from all other parts. A built up mica washer, $\frac{1}{8}$ inch, or better, $\frac{3}{16}$ inch thick, should be used at "D." Irregular and weak explosions can often be traced to a faulty insulation of this

part. If the mica washers become loose and begin to separate, dirt will get in between them and cause a partial short circuit. In this event it does little good to tighten the old washers; new, clean ones should be substituted.

Loss of Compression.

The moveable electrode should have a long, well made bearing, or better, be provided with a ground taper joint on the inside end in order to prevent the escape of the compressed charge; in fact, the whole igniter must be constructed and bolted to the cylinder in such manner as to prevent any leakage of gas. A leaky igniter is often a cause of poor compression and consequent loss of power.

The constant breaking of a circuit, with the attending spark, has a strong tendency to disintegrate and burn the contact surfaces; in fact, the current seems to tear off ex-



Wiring Diagram

Make and break ignition system.

ceedingly small particles of the metal and project them in a stream between the separating contacts. This provides a fairly good conducting path, over which the current continues to flow for a moment, and, since the current-carrying capacity of this stream of particles is small, the current heats it and partially burns it up, as it would a small wire. The surrounding gas adds fuel to this burning stream of particles and is thereby ignited. The metallic particles that are not consumed, are either lost or deposited on the negative contact. This accounts for the "pitting" of the positive and building up of the negative contact points. For this reason the igniter points must be made of some metal that will not readily disintegrate and burn.

Igniter Points.

Platinum and iridium are the best metals for this purpose. Points of pure platinum, however, are not quite hard enough to withstand the mechanical strain of being constantly beaten together, and pure iridium is so hard and has such a high melting point that it cannot be drawn into a wire or made into a rivet, but can only be formed into little globules or spheres, by allowing a drop of the molten metal to cool while falling. This iridium drop must be brazed or hard-soldered to the contact arms. A rivet made of an alloy of these metals, containing 15 to 20 per cent of iridium, is very satisfactory, and can easily be riveted to the contact arms. A form of hard nickel can be used with fair satisfaction for the igniter points where the mechanical wear and current are not too great.

There are several special alloys of nickel-steel, etc., made for this purpose, which are a great deal cheaper than

platinum and iridium, but they are in no way as satisfactory.

Duration of Spark.

The apparent momentum of an electric current is expended in a very short time after the contact points begin to separate; that is, the life of the spark or arc in Make-and-Break ignition apparatus, under working conditions, is approximately from 0.0008 to 0.005 second, as shown by the Oscillograph. This makes it necessary to separate the contact points very suddenly, in order to draw the arc out to about $\frac{1}{16}$ inch before it dies out. To accomplish this sudden break, regardless of engine speed, a spring and tripping mechanism is used. Every make of engine has its own particular design of igniter, but a glance at any one, with the requirements in mind, will make it clear.

In order to insure even and accurate timing, the tripping mechanism should be so made that wear on any of its parts, as well as on the igniter points, will not affect the time the spark occurs. The difficulty of meeting this requirement is one of the main reasons why Make-and-Break ignition is not suitable for high-speed multiple-cylinder motors.

So long as the igniter points are in contact the current flows; therefore, to save the battery, the contact should be as brief as possible. The circuit should be closed just long enough to allow the current to build up almost to its maximum, for it is evident that the spark will be strongest if the circuit is broken instantly after the current has reached its full strength, and will be no stronger no matter how long after that the circuit is kept closed.

Time Length of Contact.

The time required for the current to build up in Make-and-Break coils, depends upon the E. M. F. of the battery and the construction of the coil. With four new dry cells, the time required with different makes of coils is from 0.015 to 0.10 second. These figures are not the results of theory or guess, nor even of mathematical calculation, but are taken from the record made by the rising current itself, in an oscillograph, a description of which is given in the next chapter.

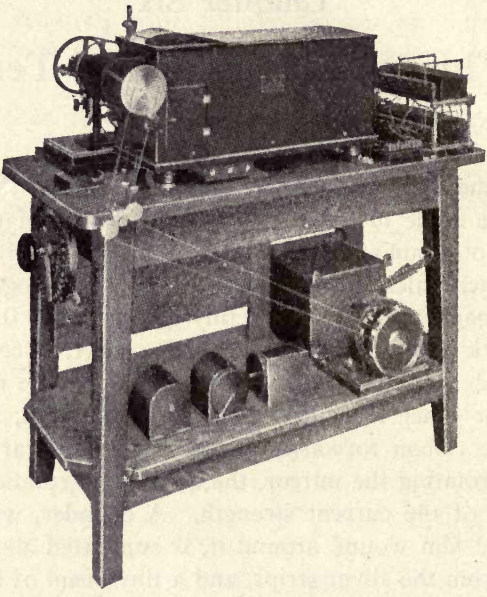
Chapter Six

The Oscillograph and Tests

The Oscillograph.

In the oscillograph, very rapidly changing electric currents are made to trace a permanent record of themselves on a photographic film. Two thin strips of silver 1/2000 of an inch thick, are suspended very close together in a strong magnetic field, and a tiny glass mirror, 0.001 of an inch thick and about $\frac{1}{32}$ of an inch square, is cemented to the strips. A current of electricity sent up one ribbon and down the other reacts upon the magnetic field, tending to push one ribbon forward and the other backward, thereby slightly rotating the mirror, the amount of rotation being a measure of the current strength. A cylinder, with a photographic film wound around it, is supported about twenty inches from the silver strips, and a tiny beam of light from an arc lantern is focused on the mirror and reflected back from it through a slot in a partition to the cylinder. The whole is inclosed in a light-tight box. The cylinder is rotated at a known speed and an electrically operated shutter allows the beam of light to strike the film for one revolution only. If the current to be measured, or a certain proportion of it, is sent up and down the strip, the mirror and beam of light will oscillate according to the variation of current. This motion of the spot of light, combined with the rotation of the film, will trace a curve on the latter. The loop of silver

ribbon with the mirror is inclosed in a glass tube, containing the damping liquid, and is so sensitive that it will respond over 6,000 times a second.

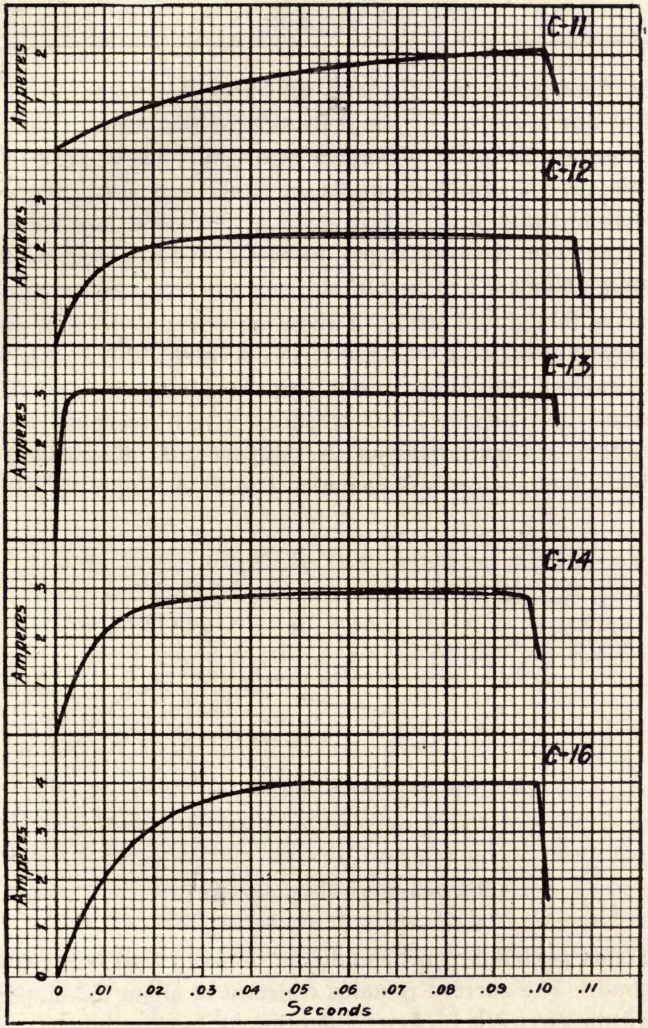


The oscillograph, a very sensitive instrument which makes an accurate record of rapidly changing electric currents on a photographic film.

The oscillograph the author has in his Laboratory has been specially arranged by him for particular research work along other lines, and being extra sensitive it is peculiarly adapted for investigating ignition apparatus.

OSCILLOGRAMS OF MAKE-AND-BREAK COILS.

The accompanying "oscillograms" were carefully traced, from the original film, on squared paper, properly calibrated



A series of records taken from the oscillograph, showing how the current builds up in various coils. The current was furnished by four dry cells working through a regular igniter arranged to make a very long contact.

for *time,* from the diameter and speed of rotation of the film; and *amperes,* by the deflection of the beam of light by a constant current of known strength. They were taken with several different kinds of coils and four dry cells working through a regular igniter, the latter, however, for convenience, was arranged to make a very long contact, namely about 0.1 of a second.

A thoughtful study of these curves will develop many interesting facts; for instance, in curve "C-12," we see that the current builds up to one ampere during the first 0.005 second and becomes 1.6 amperes in 0.01 second, finally reaching its maximum of 2.2 amperes, as determined by Ohm's Law, after 0.03 second. The time length of contact

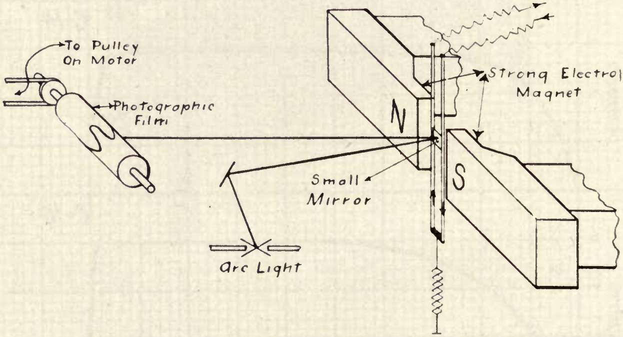


Diagram of Oscillograph.

for this particular coil should be between 0.015 and 0.020 second. The current remains constant at about 2.2 amperes until the circuit is broken, when the arc begins and the steep descent of the curve indicates the current passing through the arc. In this instance, the arc lasts a little longer than

0.001 second and dies out when the current, passing through it, drops to about 1 ampere.

Curve "C-11" is taken from the same coil as "C-12," excepting that the coil is placed in an iron box. Note how much slower the current rises and falls. In this case, the arc lasts nearly 0.003 second. This type of coil will, as a rule, consume less current than open core types, because it will permit a greater variation of time length of contact without using too much current. The time length of contact for this coil should be between 0.02 and 0.04 second. Since the time length of contact varies with the speed of the engine, and the accuracy with which the igniter is made, the advantage of an iron clad coil from a standpoint of current consumption, is obvious.

Curve "C-13" was taken from a coil *not* having an iron core. Curve "C-14" was taken from the same coil *with* an iron core, showing the difference there is between the two. A comparison of these curves proves the great importance of the iron core.

E. M. F. of Spark.

The momentary voltage produced in Make-and-Break coils has to the writer's knowledge heretofore been only estimated, for it is very difficult to make an accurate measurement, due to the many conditions affecting it. To obtain an accurate measurement of this the author constructed a commutator which connected a special electrostatic voltmeter across the arc for about one hundred thousandths part of a second. Various coils were tried, and it was found that the momentary E. M. F. was from 60 to 200 volts, depending upon the battery and coil.

Make-and-Break ignition is very satisfactory for single-cylinder, low-speed engines, provided the igniter is properly insulated and equipped with iridium or iridium-platinum points and designed to give a very sudden break, and proper time length of contact to suit a well made coil. Most of the trouble with Make-and-Break ignition is in the rapid burning and corroding of the igniter points, requiring frequent renewal and in defective insulation of the stationary electrode. Points of proper material, when used with an efficient coil, will last a whole season, and often very much longer.

Make-and-Break ignition may be said to be complicated mechanically and simple electrically, and the Jump Spark, simple mechanically, but complicated electrically. The absence of levers and heavy moving parts makes the Jump Spark system superior for high-speed multiple-cylinder engines.

Magnetic Plug System.

A form of Make-and-Break ignition, known as the Magnetic Plug system, has been devised to meet the conditions in medium speed multiple-cylinder engines. In this system, the igniter is made very small and light and is operated by an electro-magnet, the whole being enclosed in a metal shell not a great deal larger than the high-tension spark plug, and is screwed into the cylinder in the same way. When ignition is required an impulse of current is sent to the magnetic plug, across the igniter points through the electro-magnet, which then attracts its armature thereby separating the contacts.

Chapter Seven

Theory of the Jump Spark Coil

We have already pointed out that, in order to produce the spark or arc in make-and-break ignition, it is necessary that the igniter points touch each other, then rapidly separate. Since this involves considerable mechanical action, this system is unsuitable for high-speed motors. In order to properly ignite medium and high-speed engines, it is necessary to eliminate all heavy moving parts. This is accomplished in the jump spark system, wherein the igniter points are placed a short distance apart and held stationary, and the arc is started between them without previous contact. As stated in a previous chapter, this is accomplished by increasing the E. M. F. sufficiently to force a current against the high resistance of the gas lying between the points of the igniter or spark plug, as it is called in this case. The instant a current starts to flow between the points, an arc is formed, very similar to the arc in the touch spark system, except that the amperage or volume of current, passing through it, is very much less. After the arc has been started, only a few volts are required to maintain it, for the resistance of the arc[1] itself is only a few ohms, and, in some cases, less even than one ohm.

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[1] For methods of measuring the resistance of arcs of various kinds, and the E. M. F. required to start them, see "The Principles of Electric Wave Telegraphy," by J. A. Fleming, F. R. S., pages 178 and 152.

Heat of Spark.

The heat of an arc depends largely upon the amperage flowing through it. A high voltage is needed only to *start* the arc, which, when started, should be fed with considerable current. The E. M. F. required to start an arc depends upon several conditions, the principal ones being: Distance between terminals or length of spark; kind of surrounding gas—its pressure, its temperature; nature and form of terminals between which the spark jumps. We can only briefly mention the manner in which these conditions influence spark potential.

In sparks, from 1-64 inch to ¼ inch long, the E. M. F. increases almost directly as the length. The resistance of various gaseous mixtures used in internal combustion motors, at atmospheric pressure, is not very different from that of air.

Spark Voltage.

The E. M. F. necessary to produce a spark, other things being equal, varies almost directly as the absolute pressure. This law is quite accurate up to 200 pounds per square inch. Increasing the temperature of the gas lowers the necessary voltage. The writer knows of no accurate law expressing this relation; however, it has been shown that there is no simple inverse law, as the voltage decreases less rapidly than the temperature increases. The shape of the terminals between which the spark jumps, influences the necessary voltage. For instance, much less voltage is required to produce a spark between two sharp points or *from* a point *to* a flat surface than between smooth surfaces or spheres.

Many practical tests were made to determine the distance a spark should jump in air at atmospheric pressure, to insure its jumping between the points of the spark plug while igniting the engine. It was found that, for compressions not exceeding 80 pounds, a spark that would jump from $\frac{3}{16}$ inch to $\frac{1}{4}$ inch between needle points in air, would insure a jump between the points of a plug under compression in the cylinder. Many persons have made "tests" on coils and spark plugs by screwing the latter in a box, in which the air was compressed to 60 or 80 pounds, but these tests are of little value, unless the temperature of the air is raised to equal that of the gases in the cylinder. It is not easy to determine the exact voltage necessary to produce this spark, but it has been shown that the average jump spark ignition coil is capable of producing a momentary open circuit E. M. F. of from 10,000 to 25,000 volts.

Theory of Jump Spark Coil.

Let us see how the jump spark coil produces this enormous E. M. F. A jump spark coil consists essentially of an iron core, around which is wound a few turns of rather large wire, called the primary, and an entirely separate winding of many turns of fine wire called the secondary, and some means for making and breaking the primary circuit. This is really a make-and-break coil, having two separate windings. When a current is sent through the primary, a magnetic field is formed around the core, as we have seen, and the magnetic lines, when expanding or collapsing, cut through the turns of wire in the secondary winding, thereby producing in it an E. M. F. The value of this "induced" E. M. F. depends upon the density of magnetic lines, the speed at which they expand or collapse, and the number of

turns of wire through which they cut. The current, or amperage, in the secondary circuit, depends upon the value of the induced E. M. F., and the resistance of both the secondary winding and spark gap.

It is desirable to use as little current as possible and keep the resistance of the secondary winding as low as can be done. Therefore, in order to produce the necessary E. M. F. with a limited number of both magnetic lines and turns of wire in the secondary, the magnetic lines must be made to collapse as quickly as possible.

We have seen that the arc, which forms when the primary circuit is broken, allows the current and consequently the magnetic field, to die down rather slowly. If this arc were prevented, the current would suddenly be stopped and

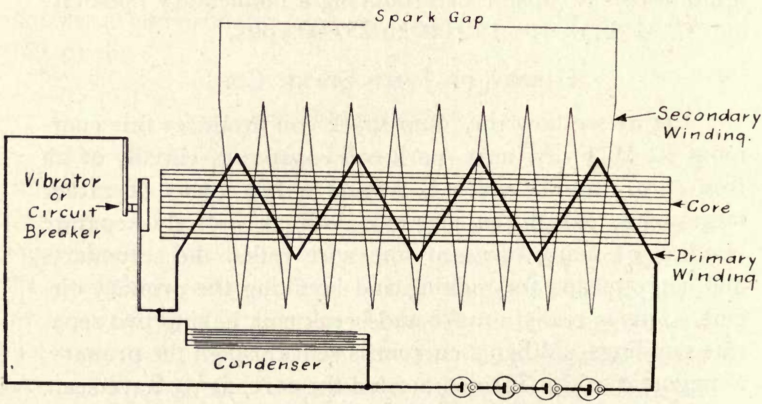

Diagram showing action of the jump spark coil.

a very rapid collapse of the magnetic lines would follow. While there are several ways for preventing the arc, such as directing a blast of air against it, or placing it in a strong magnetic field, the best method is to absorb, in a *condenser*,

the momentary "extra" current, which would otherwise form the arc.

Theory of Condenser.

A condenser consists essentially of two thin, metal strips, of considerable area, placed a short distance apart, but carefully insulated from each other. If these metal strips are connected respectively to the contact points, between which the primary circuit is broken, the "extra" current, which would otherwise form the arc, finds it easier to rush on to the strips and spread itself over their surface, thereby charging them with static electricity. After the magnetism has subsided, the condenser discharges through the primary winding, and is then ready to receive the sudden rush of current at the next break. As a matter of fact, however, the discharge of the condenser has a slight tendency to cause a more complete collapse of the magnetic lines, thereby slightly increasing the E. M. F. in the secondary. While it is impracticable to entirely eliminate the spark at the contact points it can be so far lessened as to reduce the wear on them to a minimum. The contact points in this case, as in the make-and-break system, must be made of iridium-platinum.

The secondary winding must have several thousand turns, therefore a very small wire must be used. The tremendous voltage produced demands a very careful insulation and arrangement of the turns. The secondary winding is, perhaps, the most important part of the coil.

Theory of Vibrator.

In order to produce a stream of sparks, the primary circuit must be rapidly made and broken. In the vibrating

type of coil, this is accomplished by supporting a thin piece of iron, having a contact point on it, near one end of the core. The current, from the battery, on its way to the primary winding, is made to pass through a stationary contact point, into the point on the iron head. When the core becomes magnetized the iron head is attracted; the circuit is thus broken, and the core loses its magnetism, allowing the vibrator to spring back into contact again. This process is repeated several hundred times a second. Since the vibrator is operated automatically by the magnetic attraction of the core whenever a current is sent through the primary, means must be provided for closing the primary circuit at the instant ignition is required. This is accomplished by the use of a contact maker, called the timer or commutator, which is operated by the cam shaft of the engine.

Having now a general idea of the theory of a jump spark coil, let us follow it through a complete cycle.

Complete Action of Coil.

Contact having been made at the timer, the current from the battery starts flowing across the points on the vibrator through the primary winding, where it circulates around the iron core, then back to the battery. The instant the current starts, it begins to magnetize the space around it, which effect is greatly concentrated in the primary in the manner already described. As the magnetic field is expanding, the lines of force cut through the many turns of secondary winding, thereby producing in it an E. M. F. which, owing to the comparatively low rate of expansion, is too feeble to force a current across even a very small air gap. When the magnetic field has grown strong enough to attract the vibrator armature against the tension of its spring, the

circuit is broken, and the "extra" current which would otherwise maintain itself for an instant by arcing between the points, is absorbed by the condenser and thus suddenly choked off. The magnetic lines accordingly shrink very rapidly, cutting through the secondary turns with sufficient speed to cause a considerable E. M. F. strong enough this time to overcome the resistance of an air gap and force a current across it in the form of the familiar jump spark. This spark lasts only until the energy of the shrinking lines is expended, when the vibrator is no longer attracted by the core and it springs back into contact again. The whole process is repeated with surprising rapidity.

Chapter Eight

Practical Construction and Operation of the Jump Spark Coil*

Having in the last chapter described the theory of the Jump Spark Coil, the manner of its practical construction will now be given.

The Primary.

The core consists of a number of soft Norway iron wires, Nos. 20 or 22 gage, packed tightly into a card board tube from 4 to 8 inches long, and ⅜ to ¾ inch in diameter. Around this are usually wound two layers of insulated copper wire, varying in size, according to conditions, from No. 16 to No. 20 gage. It is important that the iron wires be thoroughly annealed to make them as soft as possible, and also to give them a coat of scale which tends to insulate them one from another, thereby preventing a loss of energy through the production of Foucault or Eddy currents. A turn of oiled paper or cloth should be placed between the layers of wire, and it is well to dip the whole primary in paraffine, or better, an insulating compound having a higher melting point.

The Vibrator.

The vibrator is, perhaps, the most troublesome part of the coil to correctly design, consequently there are many different forms on the market. Since no fixed rule can be

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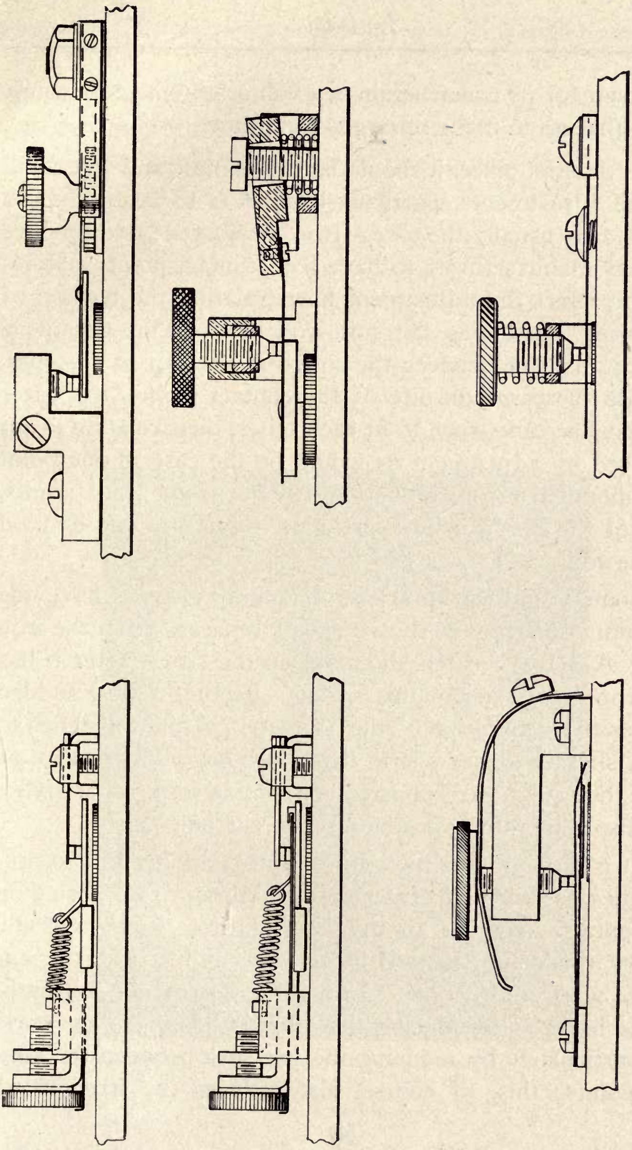
*(For a treatise on the practical construction of coils, see "Induction Coils," by A. Frederick Collins.)



Drawings showing several different types of vibrators.

laid down for its construction, we will briefly mention a few things that go to make up a good vibrator.

In the first place, it should be very simple and free from delicate adjustments, particularly if it is to be used by a novice, as is usually the case. It is considered good practice by many manufacturers to have both contact points stationary and effect the adjustment by regulating the tension of the spring supporting the soft iron head. This permits a uniform distance between the core and vibrator at all times, and also increases the life of the contact points, for, after they have become worn to fit each other, their relation is not disturbed by adjustment as would be the case if one point were mounted on an adjusting screw. Good sized points, made of the best grade of iridium-platinum, should be used for the contacts.

Some vibrators, known as "Hammer Break," have one platinum point, mounted on a spring separate from the iron head. A hook or catch, mounted on the latter, after it has begun to move, strikes this spring, effecting a very sudden and positive separation of the contacts. While this tends to give a slightly longer spark, it is more complicated, and, as a rule, not quite as responsive or rapid as some other styles, and also generally consumes more current.

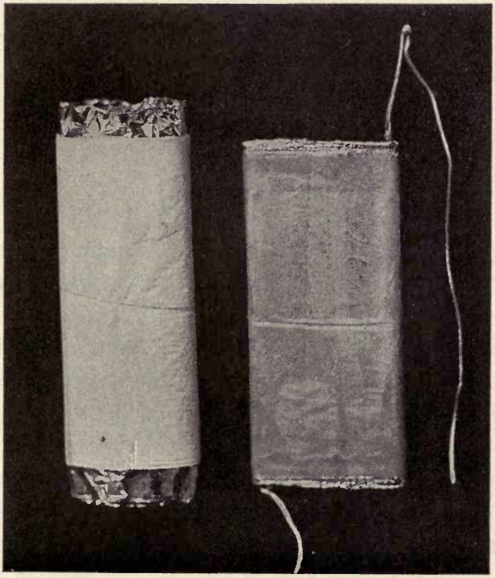
It is well to have the adjustment so designed as to prevent the possibility of "freezing" the vibrator; viz., bringing the contacts together so tightly that they cannot vibrate, thereby rendering the coil inoperative and causing an excessive waste of current. As a rule, the current consumption is lessened by placing the vibrator closer to the core, and particularly by reducing the pressure between the contact points; this, of course, also reduces the strength of

spark. Therefore, to adjust a vibrator to be economical in current, reduce the pressure between the points as much as possible, without causing the engine to miss fire.

The Condenser.

There are several ways for making a condenser, but only one of the best will be mentioned.

Two strips of very thin tin foil, separated by a double thickness of special paper, are wound into a compact roll, then soaked for several hours in hot wax. After the paper is thoroughly impregnated, the condenser is placed under a pressure of several tons, which squeezes out all surplus



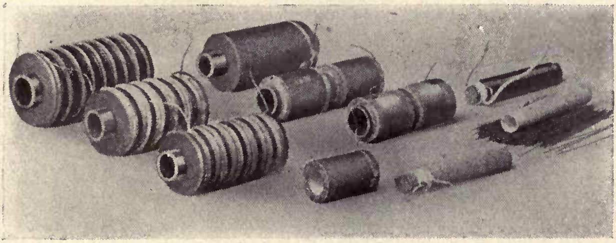
Condenser shown on the left—before soaking in wax. Finished condenser on the right, after it has been impregnated and subjected to several tons pressure.

wax, and, after cooling, it is as compact as a board. This does away with troublesome air spaces between the layers of paper and foil, and insures a minimum and uniform distance between the tin foil sheets. The importance of this is apparent when we remember that the capacity of a condenser, other things being equal, varies inversely as the distance between the tin foil sheets. It is also desirable for the condensers to be of uniform capacity. The connecting wires are soldered respectively to the folded edges of the two tin foil strips, as the photograph shows.

As the condenser of an ignition coil is subjected to sudden surgings of potential reaching several hundred volts, the insulation between the tin foil strips must be very good to prevent a breakdown. The actual capacity of condensers used in various ignition coils, is from 0.1 to 0.4 Microfarad.

Secondary Winding.

When it is realized that a current under a pressure of 10,000 to 20,000 volts is produced and made to circulate many times in the secondary of an ignition coil, it is needless to say that the most careful arrangement and insulation of the turns are necessary. The conventional method of making the secondary consists in winding a fine insulated wire in even layers around a paper tube, just large enough to slip over the primary, the layers of wire being separated one from another by one or two turns of thin paper. When the required number of layers are wound, which is usually between 30 and 50, the coil is soaked for several hours in melted wax. In order to insure thorough and uniform insulation, it is best to use the *vacuum impregnating process*,

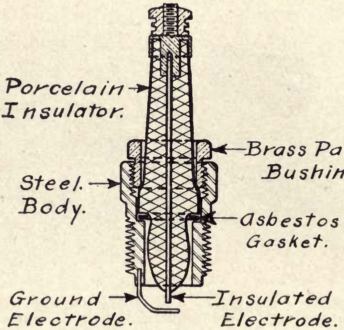


A group of secondary windings. The three on the left are wound by the Pancake system. The small winding in the foreground is taken from a very cheap coil. A pile of iron core wires with a finished primary are shown on the right.

which consists essentially of thoroughly drying the winding in an oven in which a partial vacuum is created. The melted wax is then allowed to flow into the oven under pressure. This helps to force the insulating compound into the center of the winding, and also drives out all trace of moisture. Where the layer method of winding is used, it is almost necessary to employ the vacuum process to secure satisfactory insulation. In order to lessen the danger of a breakdown or "burnout" of the secondary, it is usually wound in two separate parts, which are connected in series. To prevent a spark passing from one section to the other, a space is left between them which is filled with wax.

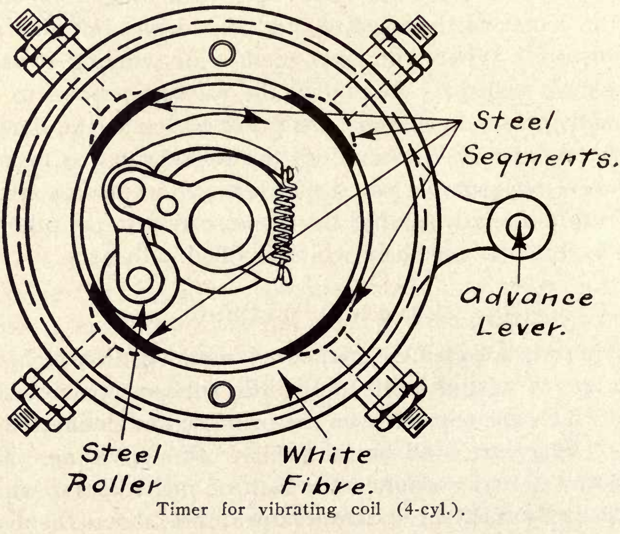
"Pancake" Winding.

There is a patented method of winding, in which the secondary is wound in 10 to 16 little rubber spools or sections, which are slipped over the primary and connected in series. The wire used has a special cotton covering. The spools are actually wound in a bath of melted wax, which is constantly kept at a temperature just above the boil-



Showing general scheme of high tension spark plug.

ing point of water. This insures the complete saturation of every inch of wire and also makes air spaces and moisture within the winding impossible. In this construction, known



Timer for vibrating coil (4-cyl.).

as the "pancake method," the insulation runs at *right angles* to the core, making the difference of potential increase with the *length* of the winding, instead of its *height,* which latter is the case in the layer method, where the insulation runs *parallel* to the core. In the layer winding, the maximum difference of potential exists between the top and bottom layers, which are not often separated more than ½ inch, and, if there is a flaw in the insulation, particularly at the ends, a breakdown may occur. This, however, does not often happen in a modern well made vacuum impregnated coil. In the "pancake" winding, the greatest difference of potential is between the two *ends* of the winding, which are from 3 to 5 inches apart. A breakdown in this winding is practically impossible.

There are several other advantages to be gained by the "pancake method" of winding; among others, the elimination of electrostatic capacity and self-induction of the winding which tends to produce a very responsive and quick acting coil.*

The secondary windings of ignition coils contain from 8,000 to 25,000 turns, depending upon the make of coil. The size of wire used is between No. 34 and No. 38 B. & S. gage.

Balance of Parts.

All parts of a coil must be carefully designed to work well together. For instance: If the condenser is too small or sluggish in action, the contact points will often flash and quickly burn, and, on the other hand, if it is too large, the secondary spark will be shortened and tend to hesitate be-

*See *"Induction Coils,"* by Armagnat, pp. 41, 44 and 78.

fore jumping, particularly if made to pass between round, smooth surfaces. The size and number of turns of wire on the primary is determined largely by the quickness and responsiveness of the vibrator. Many other things have to be worked out, for it is not a simple matter to correctly design a coil.

After the coil and condenser are assembled in a box or hard fiber tube, the latter should be filled with a good insulating waterproof compound that will not melt in hot weather or if installed in a hot place.

Chapter Nine

Oscillograph Tests of Vibrating Coils

It is well known that an ammeter, connected in series with a vibrating coil and battery, will indicate from $\frac{1}{4}$ to 1 or more amperes. Since the vibrator is constantly interrupting the current, it is evident that the current passing through the coil is not steady, but is a series of separate impulses, and that the ammeter simply indicates their average value.[1] The oscillograph[2] is the only instrument that is quick and sensitive enough to accurately record the current impulses. The accompanying oscillograph tests were made on several well known makes of coils, operated by a regular roller timer and storage battery. Each group of lines indicates one contact at the timer, and each line shows the current used each time the vibrator breaks the circuit. A careful study of these records will develop many interesting facts. For lack of space, brief mention only of a few of the most important will be made.

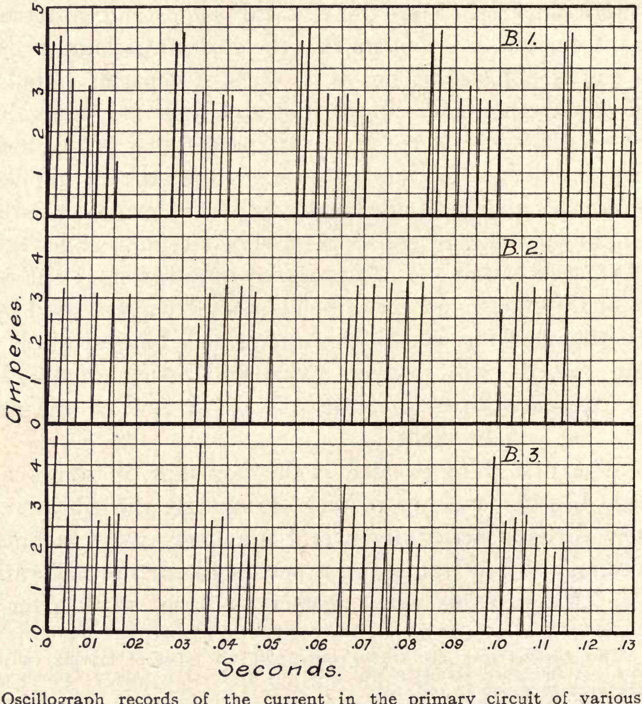
The first thing noticed is the fact that, in some cases nearly five amperes are required to operate the vibrator; in other words, a series of current impulses, each reaching a maximum of 2 to 5 amperes, is needed to operate a vibrating coil. This explains why a battery will not work after its

[1] This reading may not be the same with all types of moving coil ammeters. A hot wire ammeter will give the root mean square (square root of the average square).

[2] See Chapter Six, page 43.

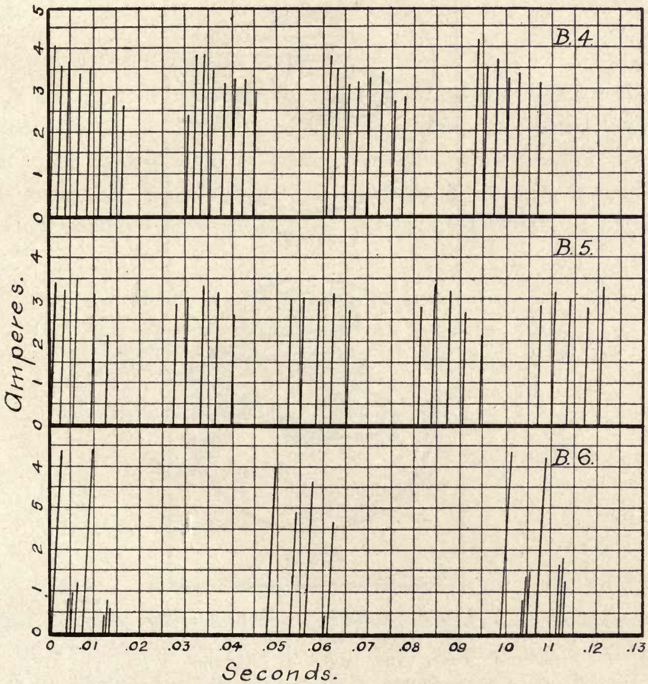
amperage is reduced below a certain limit, and also that comparatively large wires, namely No. 12 or No. 14 gage, should be used to make the connections, and still larger wires if the battery is placed more than a few feet from the coil.

It also will be noticed that in some coils the *first* impulse of the vibrator requires *more* current than the succeeding ones, and in others *less* current is required. The vibrator breaks the circuit several times during one contact



Oscillograph records of the current in the primary circuit of various vibrating coils.

at the timer, causing as many separate sparks at the plug. If the first spark, which occurs the first time the vibrator breaks the circuit after contact is made at the timer, is too weak to ignite the charge, ignition will be delayed until the second or third interruption occurs. This partly accounts for the so-called "lag" in some kinds of coils. Curve "B 2" illustrates this kind of a vibrator. Curve "B 3", on the other hand, is from a coil that takes more current for the first impulse of the vibrator than the succeeding ones; con-



Oscillograph records of the current in the primary circuit of various vibrating coils.

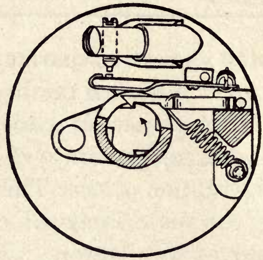


Fig 1

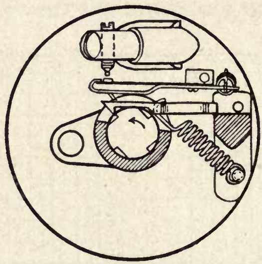


Fig. 2.

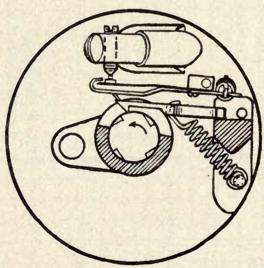


Fig. 3

Contact Breaker for non-vibrating coil, which cannot stop on contact and gives a uniform length of contact at all speeds.

sequently the spark, resulting from this first impulse, will be stronger than the following ones, and will invariably ignite the charge. In this case the several following sparks do no good and it will also be noticed that the current required for these extra sparks is comparatively small. This type of coil has very little "lag," and is, therefore, particularly good for high-speed motors. It will not work, however, quite as well on an old battery low in amperage as the other type (B 2), unless a multiple battery is used. Curve "B 6" represents the very irregular action of a poorly designed vibrator working on an improperly balanced coil.

Non-Vibrating Jump Spark Coils.

A mechanical circuit breaker is often substituted for the vibrator, and geared to the engine, so as to break the circuit the instant ignition is required. In this system only one spark occurs at the plug, but, if it is strong enough, it is all that is needed. Fig. 6 illustrates this type of timer, as used

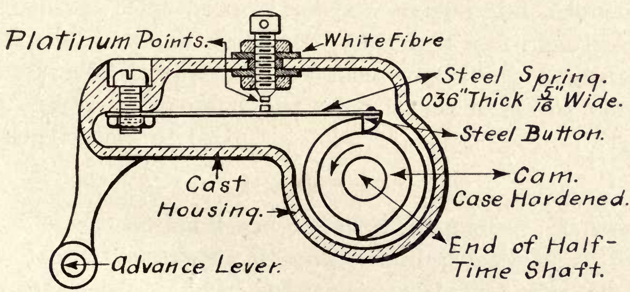


Fig. 6. Timer for non-vibrating coil.

on motorcycles and many types of small stationary engines. The fact that this timer can stop with the points in contact is an objection, because when this happens, the battery

is rapidly used up. Figs. 1, 2 and 3 clearly show a contact breaker which can never stop with the points together. The time length of contact, and therefore the strength of spark, is the same at all engine speeds. This apparatus uses very little current.

Chapter Ten

Dynamic Electricity

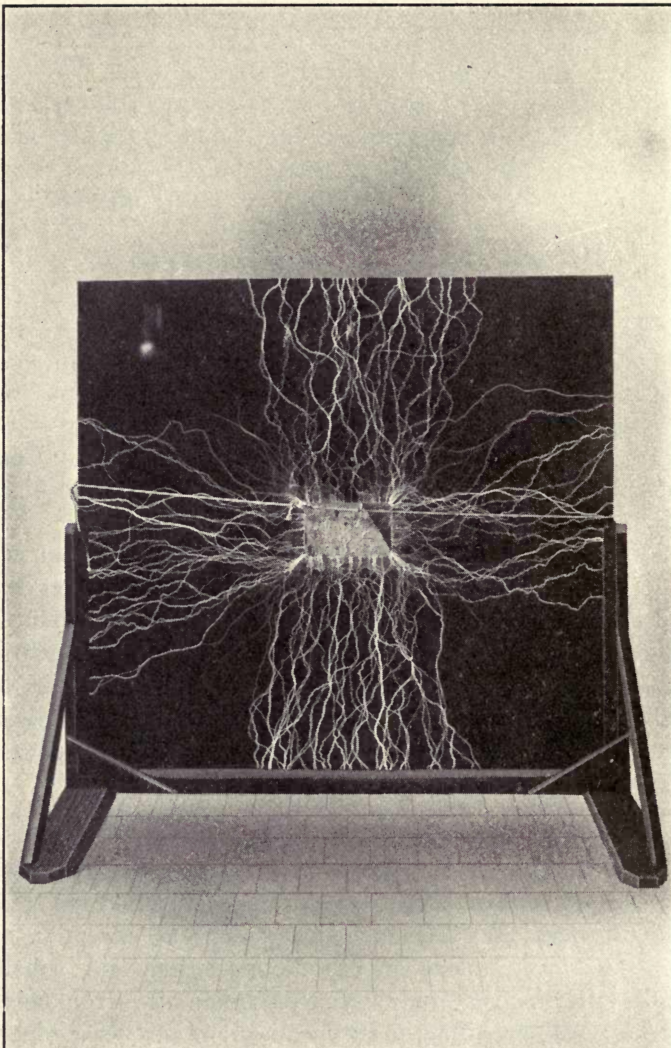
HOW AN ELECTRIC CURRENT IS PRODUCED BY MECHANICAL MEANS IN DYNAMOS AND MAGNETOS.

In the Introductory it was stated that there are two principal methods for producing an electric current, viz.: Galvanic or chemical, and Dynamic or mechanical. Consider now how an electric current can be produced by mechanical means.

As already mentioned, electricity and magnetism are very closely related. An electric current magnetizes the space around it; in other words, an electric current produces magnetism. This process can be reversed and magnetism made to produce an electric current. It is well right here to call attention briefly to a few facts concerning magnetism, and clearly fix in mind just what is meant by the phrase "magnetic lines of force."

MAGNETISM.

There is no known insulator of magnetism. It passes quite freely through the air, and, with practically equal freedom, through all other substances, with the exception of iron—and its various modifications—nickel and cobalt. These latter metals offer a better path than air. Iron, being the best, will, according to its chemical and physical properties, conduct magnetism from 100 to about 10,000 times better than air. Magnetism, like electricity, can flow only in



Sparks from a 30-inch induction coil playing around a glass plate five feet square—an artificial thunder and lightning storm, making a noise like a broadside of gattling guns.

closed circuits. Every magnetic line of force is assumed to pass *out from* the north (+) pole, and make a complete circuit through the surrounding medium and return *into* the south (—) pole, then through the magnet to the north pole again, and so on. The path through which the lines

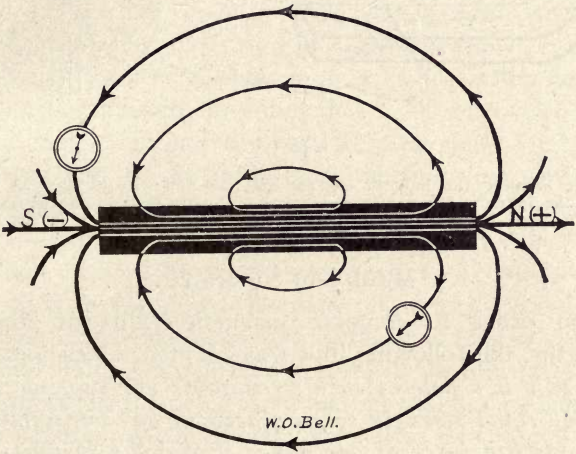


Fig. 1.

Diagram showing the path or circuit taken by the magnetic lines of force around a bar magnet.

of force travel, is called the magnetic circuit, and, like an electric current, the amount of magnetism that will flow, other things being equal, depends upon the resistance or *reluctance,* as it is called, of the magnetic circuit. The region near the poles of a magnet, traversed by lines of force, is spoken of as a magnetic field. The directions taken by the lines of force can be shown by placing a small compass in the magnetic field. The needle will swing around so as to be parallel (or tangent) to the lines of force, and its north pole will point in the direction of the magnetic lines.

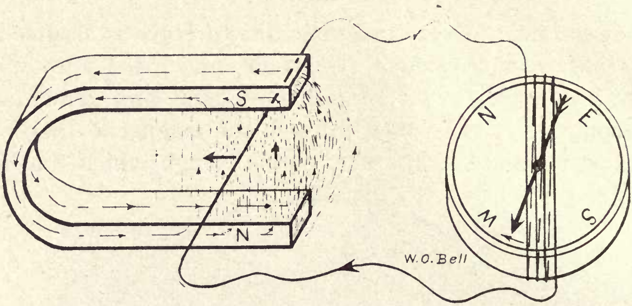


Fig. 2.

Diagram showing the induced current and the direction it takes in a wire, as the latter is being moved across a magnetic field in the direction shown by the arrow. The compass needle will turn in the direction indicated.

Magnetic Strength.

In order to compare magnetic fields of different strengths, the following unit was adopted: *The unit magnetic pole is a pole of such strength as will repel a similar pole of equal strength when placed in air, one centimeter away, with a force of one dyne.* Imagine a magnetic pole of unit strength, placed in the center of a sphere having a radius of one centimeter; a certain quantity of magnetism will pass through every square centimeter of the surface of the sphere. This particular amount has been adopted as the unit quantity of magnetism, and is known as one *line of force.* The name *"Maxwell"* after J. Clerk Maxwell—the first great mathematical electrician—is often substituted for the phrase "line of force," and so a magnetic field, through which 20 lines of force pass, may be said to have a strength of 20 maxwells. Since the surface area of a sphere of radius "r" equals $4\pi r^2$, the area of a sphere having a radius of one centimeter is 12.57 square centimeters. From this it

follows that every magnetic pole of unit strength sends out 12.57 lines of force or maxwells.

Magnetic Density.

The unit of magnetic or "flux" density is called a *gauss*, and is *that density resulting when one maxwell passes at right angles through an area of one square centimeter;* hence a magnetic field may be spoken of as having a flux density of, say 5,000 gausses, meaning that 5,000 maxwells pass, at right angles, through every square centimeter.

In the light of the above facts, the following statement of the fundamental principle of dynamo electric generators will be readily understood: *Whenever a conductor and magnetic lines of force are made to intersect one another, an E. M. F. is produced in that conductor, and, if its ends are connected, thereby completing the circuit, an electric current will flow.* This phenomenon can easily be illustrated by passing between the poles of an ordinary horseshoe magnet, a wire having a galvanometer included in its circuit. If a galvanometer is not handy, make one by winding a few turns of insulated wire around a pocket compass, as shown in Fig. 2. Note that the compass needle will swing in one direction when the wire is *entered* between the poles of the magnet, and in the opposite direction when it is *withdrawn.* This shows that the direction taken by the so-called "induced" current depends upon the relative direction of motion of the wire through the magnetic field.

The value of the E. M. F. so produced, depends directly upon the three following conditions: The density of magnetic flux, through which the wire passes; the length of "active" wire—that part of the wire that actually cuts through the magnetic flux; and the speed with which the

wire is passed across the magnetic field. The current or amperage depends, as we already know by Ohm's Law, directly upon the E. M. F. and inversely upon the resistance of the circuit.

Fig. 3 illustrates the principles of a direct-current electric generator. The magnetic field is furnished, in this case, by a permanent magnet. The wire which cuts through the lines of force is a single turn, rectangular in shape, and mounted on a shaft. When the latter is rotated in the direc-

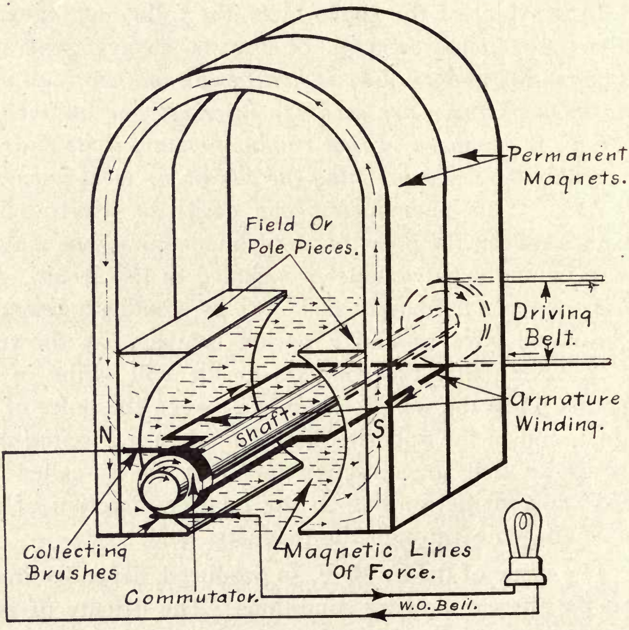


Fig. 3.

Diagrammatic view of simple generator, showing, respectively, the direction of rotation, magnetic lines of force, and induced current.

tion indicated by the arrows, both long sides of the winding will cut through the lines of force in such manner as to cause a current to flow in the direction shown by the arrows. In Fig. 3, the armature is in the most advantageous position, that is, the maximum number of lines of force are being cut, and, consequently, the current is at its maximum. As the armature continues to rotate, the number of lines of force being cut becomes gradually less and less, until, after revolving a quarter of a turn the position shown in Fig. 4 is reached where *no* lines of force are being cut and the current accordingly has dropped to zero. As rotation continues, the winding begins again to cut the lines of force,

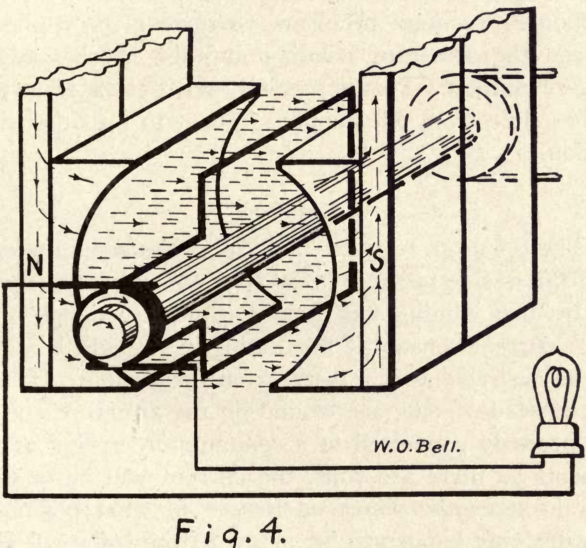


Fig. 4.

Same as Fig. 3, except armature has advanced 90 degrees and is NOT—cutting any lines of force, therefore no current is produced.

reaching a maximum at the next quarter revolution, when the current is once more strongest. In this manner, the current fluctuates between maximum and zero values, two impulses of current being produced every revolution.

Collecting Brushes.

The current from the armature winding is collected by means of two copper brushes, bearing against a split copper ring, each half of which is connected to an end of the armature winding. Observe that, as the armature revolves, the current produced in the winding reverses its direction twice in a revolution. In order to make the current, taken away from the machine by way of the brushes, flow in one direction, it becomes necessary to reverse the connections between the armature winding and the brushes twice in every revolution. This is precisely what takes place as the brushes slide from one copper segment to the other during rotation.

Commutator.

These copper segments are called the commutator and serve the double purpose of leading the current away from the armature winding and making it uni-directional.

A current constantly fluctuating in strength is not, as a rule, as desirable as if it were of uniform value. If several coils, instead of one, are wound on the armature and their ends properly connected to a commutator, having as many segments as there are coils, the current will be quite uniform in strength; since, no matter in what position the armature may happen to be, a few of the coils will always be cutting the lines of force. The greater the number of coils there are, the more steady will be the current.

Magnetic Circuit:

We have already seen that the value of the induced E. M. F. depends among other things upon the strength of the magnetic field. In order to make the magnetic field as strong as possible, the reluctance of the magnetic circuit must be reduced to a minimum. Obviously, most of the reluctance of the circuit is in the air gap between the pole pieces. If this air gap were filled with soft iron, the reluctance would be very greatly reduced, and the magnetic density thereby increased many times. The only way this can be accomplished, for obvious reasons, is by winding the coil around an iron cylinder or drum, and allowing it to rotate with the armature. The drum, or armature core, is made to fit the pole pieces, allowing only the necessary clearance, and the winding is placed in grooves, parallel to the axis of rotation. In order to prevent so-called Eddy

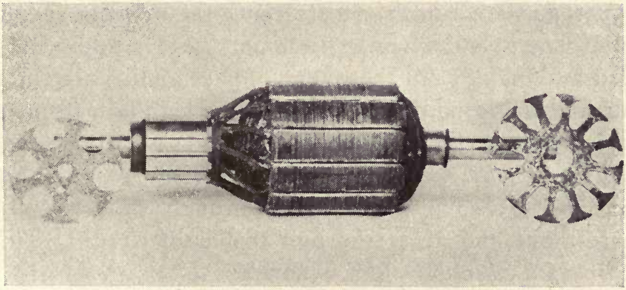


Fig. 5—Photograph of a "drum" wound armature, showing commutator and several coils, and two types of soft iron armature discs.

currents from being produced and circulating around in the iron core, the latter is usually built up of many thin, soft iron discs, coated with varnish, to insulate them one from another.

Armature.

The accompanying photograph shows a finished "drum" armature, taken from a small six-volt dynamo. The greater the number of turns of wire in each coil of the armature the higher will be the voltage. In small, low-tension machines for ignition service, giving four to ten volts, there may be anywhere from 10 to 50 turns in each coil. Of course, the voltage increases with the speed of rotation. There are a few other ways for winding an armature, but the principles involved are exactly the same. The drum armature, however, is the most popular. If some one could design a generator that would give a uniform voltage, regardless of speed, and without complicated governors, etc., a long-felt want in the ignition field would be filled.

Difference Between Magneto and Dynamo.

When the magnetic field is furnished by a permanent magnet, as shown in the illustrations, the machine is known as a *Magneto,* and when an electro-magnet is employed, it is called a *Dynamo.* In the dynamo, part of the current generated by the armature is used to energize the field magnet. When the two ends of the field winding are connected respectively to the two brushes, the current from the armature divides, a small part flowing through the field coil and the rest out and away through the main circuit. This is known as a *Shunt Wound* dynamo.

If a dynamo of this type were short-circuited, a powerful rush of current would take place, lasting, however, only a moment, then all generation of current would cease. This is due to the fact that the current would no longer divide at the brushes, but all of it would flow across the short circuit and leave nothing to energize the field magnet, which

would then rapidly lose its magnetism, when, of course, no current could be generated by the armature. When the machine is at rest, there is practically no magnetism in the field; a very little only is retained by the soft iron of the field core. When the dynamo is started, this "residual" magnetism is usually strong enough to produce, in the armature, a feeble current, which flows into the field winding, thereby strengthening the magnetic field.

Shunt Wound.

Quite often a dynamo, particularly if it has been idle for a long time, will not, when started up, begin to generate current or "pick up" at once. This may be due to a lack of residual magnetism, and, if a battery is connected for a moment to the field coil, the machine will invariably pick up immediately. The polarity of the battery may have to be reversed, before meeting with success. If a Shunt Wound Dynamo is connected to a circuit of too low resistance, most all of the current will flow over this circuit, and there will not be enough left to properly excite the field. Under these conditions, the dynamo will give out only a fraction of its capacity. In this event, the resistance of the main circuit should be increased or a dynamo, wound for a lower voltage, used.

Series Wound.

If the field winding is of large size wire, and connected in series with the armature, the total current will flow through the field coil on its way to the main circuit. A dynamo, connected in this way, is said to be *series wound.* The Shunt connection is generally used, however, as it is less troublesome.

The variation of voltage with speed is greater in a dynamo than in a magneto, because, in the former the strength of the field changes with the speed, and in the latter the magnetic field is always constant. For this reason, a magneto generator is not so dependent upon the circuit with which it is connected.

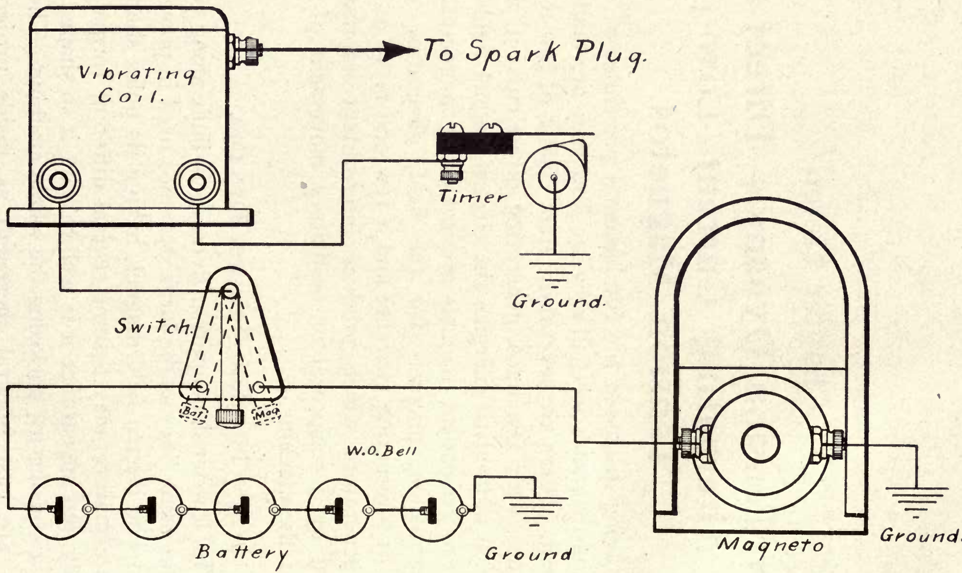
Chapter Eleven

Low-Tension Dynamos—Direct and Alternating Current—Low-Tension Magnetos

Having discussed the fundamental principles of dynamos and magnetos we will now see how they are made and operated. There are several different classes of low-tension machines, viz.: Dynamos, generating direct current, a part of which is used to energize the electro-magnet fields, and therefore permanent magnets are *not* used; magnetos, having permanent magnets for the field, generating either direct or alternating current; and a few odd types of magneto generators which produce intermittent impulses of current by a reciprocal or oscillatory movement of some part of the machine.

The Low-Tension Dynamo.

The low-tension ignition dynamo is built along practically the same lines as the large dynamos used in power stations. The electro field magnet, having its poles shaped to fit the armature, may assume several different forms. For stability and appearance it is well to have it so shaped as to act as a housing for enclosing the whole machine. The pole pieces are cast integral therewith as inside projections, around which are placed the field windings. The armature is usually of the "drum" type and may have from six to



Wiring diagram for low tension magneto, with set of dry cells for starting.

twelve coils wound with double cotton covered wire, carefully insulated from the armature core. The coils should be given a thick coat of some oil and heatproof insulating varnish. If the winding of the armature is not carefully done, one or more of the coils will, sooner or later, become short-circuited or grounded, and the output of the machine seriously impaired. If the armature is run at high speed as is usually the case, binding wires should be placed around the armature to prevent the coils from flying out of place by centrifugal force.

THE COMMUTATOR.

The commutator is another delicate part to manufacture. The copper segments must be securely held in place and insulated one from another and the ground, by a special form of mica. The ends of the coils are placed in grooves in the commutator segments and soldered. The armature is then placed in a lathe and the commutator turned perfectly smooth and polished. The brushes are usually made of copper gauze, rolled or folded under pressure into a short rod, one end of which is dipped into melted solder, to keep it from unravelling. A spiral spring is also attached to it. These brushes are often made with a little graphite, which reduces the wear on the commutator and prevents cutting. Carbon rod, made with graphite, wears better than any other material, but, owing to its comparatively high resistance, it is not often used for low-tension machines. This objection, however, can be overcome, to a large extent, by heavily copper-plating the carbon. Care should be taken that good electrical contact is always maintained between the brush and the brush holder. Missing explosions can often be traced to a brush that is not in good contact with its

holder. The spring should be just stiff enough to hold the brush firmly against the commutator. If it is not stiff enough, sparking is likely to occur, which will burn and roughen the commutator, making good contact impossible. In this case the armature should be placed in a lathe and the commutator smoothed up with very fine sand paper, and then rubbed with a piece of oily waste, if a stick of regular commutator compound is not handy.

Since the brushes and commutator are responsible for nine-tenths of the trouble with direct-current dynamos and magnetos, a frequent inspection of these parts is greatly desirable. If the commutator is well made, protected from dust and dirt, and large brushes are used and inspected once in a while, there is no excuse for trouble of any kind.

Where current for ignition only is needed, the dynamo has been largely replaced with the direct-current magneto, but where it is also required to furnish current for several small electric lamps, as for an electrically lighted automobile or small launch, the dynamo is usually used.

In order to get the best results from a spark coil, and particularly from low voltage tungsten lamps, it is necessary to keep the voltage applied to them uniform in value. This is often accomplished, to a certain extent, by building a governor into the machine, which does not allow the armature to rotate above a certain speed. Most governors, however, do not work accurately enough to keep the voltage as uniform as it should be for tungsten lamps. To further regulate the voltage, the dynamo is often connected to a storage battery in such a manner as to be constantly charging it while the battery is supplying current for the ignition and lamps. A switch worked by an electro-magnet, or by a

governor on the dynamo, must be provided to disconnect the battery from the dynamo, when the latter is stopped or not up to speed, otherwise the battery would send a current through the winding of the dynamo and rapidly discharge. If, on the other hand, the dynamo is allowed to run all the time, continually charging the battery, when the

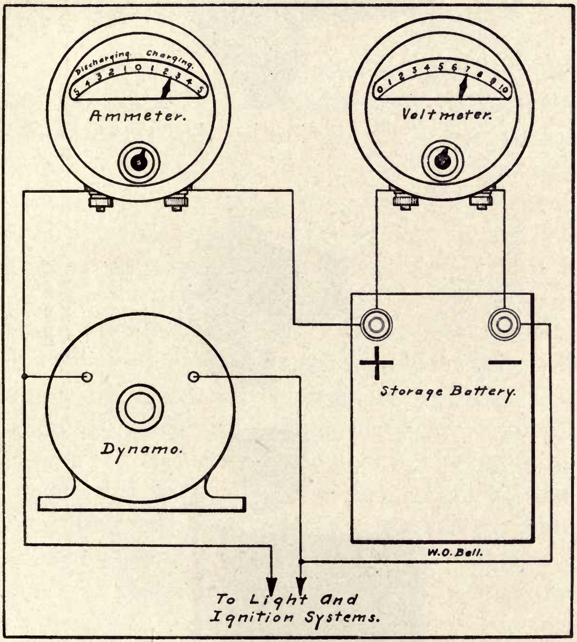
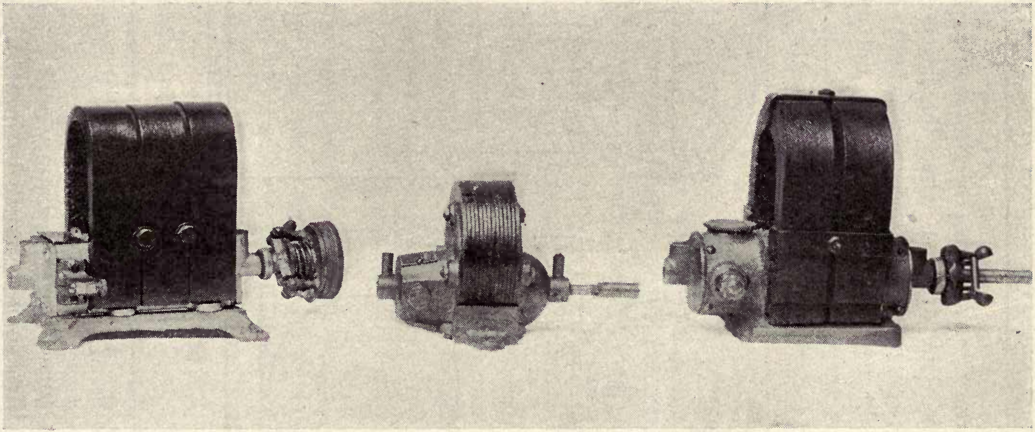


Diagram showing the connections for a combination ignition and lighting system known as "floating the battery on the line."

lights are not turned on, the battery will become overcharged, and, if prolonged, it will be injured. There are storage batteries with liquid electrolytes, made especially for



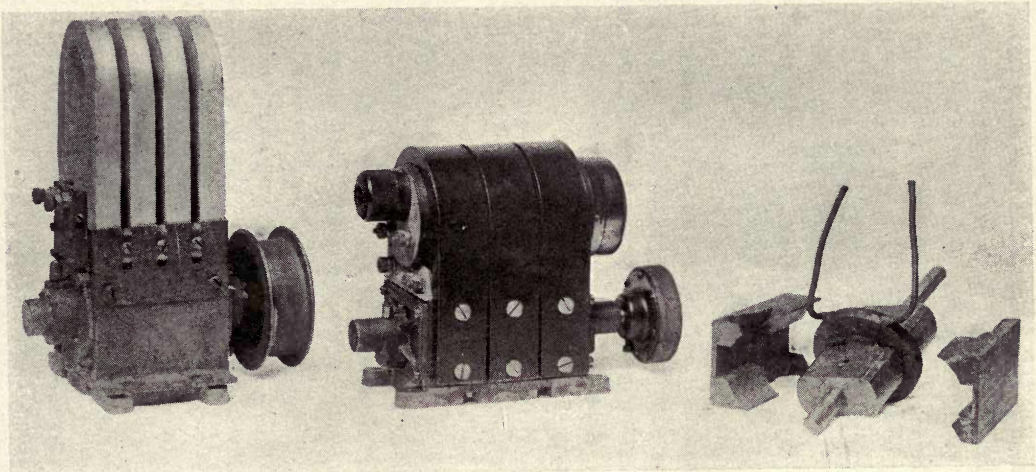
A group of direct current magnetos for supplying current to jump spark or make-and-break coils.

this service, that will stand considerable overcharging. The water in the electrolyte will, however, be "boiled" out and must be replaced, from time to time, with pure, distilled water. It is very important to keep the electrolyte well above the plates of the cells at all times. It is a very good thing to install a low-reading zero-center ammeter in series with the battery, and a voltmeter in multiple with it, as shown by the diagram. When the pointer of the ammeter swings to the right, the battery is being charged, and to the left, discharged. The voltmeter will indicate the condition of the battery. If a regular six-volt battery is used and the voltmeter shows 7 to 7.5 volts, *while the battery is charging,* at a rate of 2 to 4 amperes, the dynamo should be disconnected, since the battery is fully charged. This system is known as "floating the battery on the line," and will give excellent results if a little care is used in handling it.

There are several special methods for regulating the output of dynamos, such as having the governor, instead of regulating the speed of the armature, control a variable resistance, in series with either the field winding or the main circuit; or by having a compound winding on the field so arranged with an electro-magnetic mechanism that, when the voltage exceeds a certain value, the field windings will oppose each other. We cannot, for lack of space, go into the details of these various systems, as the manufacturers furnish descriptive matter and instructions for their own particular systems.

The Direct-Current Magneto.

The direct-current magneto is exactly the same as the dynamo, except that permanent magnets are used for the



Two alternating current inductor type magnetos. The one on the right has a special vibrating coil mounted under the arch of the magnets. Note the peculiar shape of the pole pieces, inductor and stationary winding, shown on the extreme right.

field. The armature, commutator and brushes require the same care as in the dynamo.

Direct-current magnetos are usually made a little smaller and cheaper than dynamos, and are more popular where current is wanted for ignition only, or for one or two small tungsten lamps. The magneto has an advantage over the dynamo, in that the strength of the field magnet is the same at all speeds. This allows the magneto to generate current at a slightly lower speed than the dynamo, and the variation of voltage with speed is not as great. If the magnets are carefully made by up-to-date methods, from the best special magnet steel, they will last for several years, without recharging. It is very important in installing a magneto, to make sure that the voltage it gives is suited to the coil that is to be used with it. If the voltage is too high, the contact points on the coil will soon burn up, and, if too low, the vibrator will not work and the engine will miss fire. If the magneto and spark coil are purchased from two different concerns, one or both of the manufacturers should be consulted, as to whether or not the combination will work satisfactorily. Some magnetos will give current enough to operate the coil when the engine is cranked over, but, in many cases it is best to provide a battery for starting.

The Alternating Current Magneto.

When an electric current is constantly changing in strength and periodically reversing its direction, it is known as an alternating current. Alternating current magnetos cannot, under any condition, be used to charge storage batteries. Some alternating current magnetos have one coil only on the armature, and give one positive and one nega-

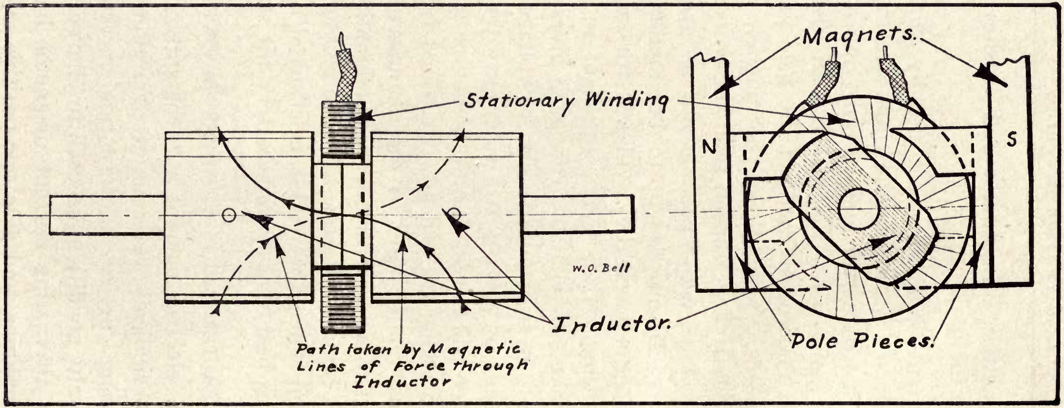


Diagram showing the method of shifting magnetic lines of force through the stationary coil of an inductor type magneto.

tive impulse of current every revolution. This type of magneto must be geared to the engine in such a manner that the current wave will be at its maximum value at the instant ignition is required. One end of the winding is usually grounded on the armature core, and the other end is brought to an insulated copper ring, against which bears a collecting brush. While this collecting ring and brush is less troublesome than a regular commutator, it should occasionally be cleaned and inspected.

THE INDUCTOR TYPE ALTERNATING CURRENT MAGNETO.

There are a few patented alternating current magnetos on the market, which have no commutator, brushes, collecting rings or moving wires of any kind. An alternating current is induced in a stationary winding by rapidly shifting the magnetic lines of force through it. The only moving part of the machine is a soft iron member called the inductor, which is so shaped as to cause the magnetism to alternate through the coil four times in one revolution, thereby producing four impulses of current—two positive and two negative. Referring to the drawing, the full line shows one path taken by the magnetic lines through the soft iron inductor and stationary winding, and the dotted line shows the other path in the reverse direction. Inductors were tried which gave six and even eight alternations of magnetism per revolution, but it was found that, at high speed, the magnetic lines could not reverse through the inductor rapidly enough and so the current impulses were too weak to satisfactorily operate a coil. Four impulses of current per revolution is the most satisfactory. Care must be taken in designing an inductor type magneto to see that the pole pieces and inductor are so shaped as to cause the magnetic

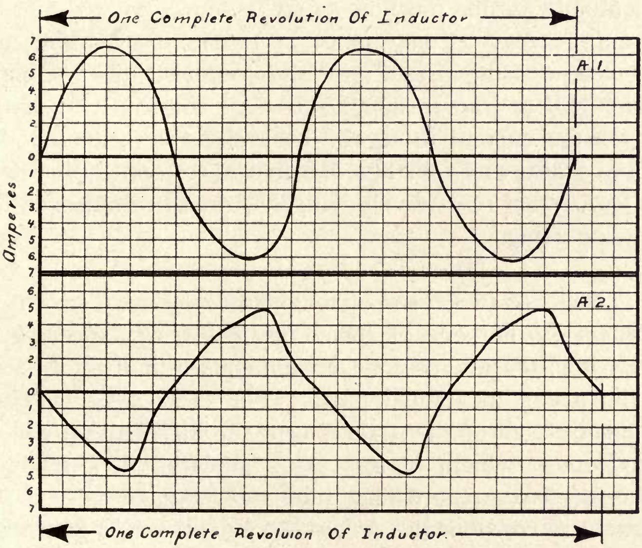
reversals through the winding to be as uniform as possible, in order to insure what is known as a "Sine Wave." While there are four impulses of current per revolution, there are also four times when the current is zero. It is evidently desirable, then, to have the time during which little or no current is being produced, as short as possible. The two oscillograms show the current wave forms of two different inductor type machines. Notice that one wave is more "peaked" than the other.

If a machine, giving four impulses of current per revolution, is speeded up to 2,000 revolutions per minute, there will be 8,000 impulses of current per minute, or 133 every second. When this is used as a source of current for a vibrating coil, working through a regular timer, it is evident that the timer may happen to make contact at the instant when little or no current is being produced. When this happens, the vibrator must wait until the next impulse or wave becomes strong enough to operate it. This will delay ignition for an instant, but, owing to the rapidity with which the impulses follow one another, the delay is too short to cause any appreciable loss of power, except, perhaps, in some very high-speed motors.

All styles of coils will not, as a rule, work satisfactorily on the inductor type magneto, since the vibrators and primary windings will not respond on the rapidly alternating current. A special coil, or at least a special master vibrator, designed to work on alternating current, should be used with inductor type magnetos.

These machines can be driven by the flywheel with a friction pulley, or belt, and should always be kept up to speed as recommended by the manufacturers. About the

only advantage an inductor type magneto has over a direct current machine is the entire absence of all brushes, commutators, collecting rings and moving wires. The variation of voltage with speed is also less than on direct-current machines, due to the more rapidly increasing impedance of the winding with speed. On the other hand, they have the disadvantage of not being able to work successfully on all types of coils, or to charge storage batteries.



Oscillograph records, showing the current wave forms of inductor type magnetos. At 2,000 revolutions per minute of the machine there are 133 of these impulses every second.

Chapter Twelve

High-Tension Magnetos—Their Theory and Construction

Having described a few different types of low-tension machines it remains to speak of the high-tension magneto. It combines in one machine—first, a source of low-tension current; second, a commutator or timer, to allow the current to flow at the instant ignition is required; third, a high-tension coil or transformer, to increase the E. M. F. of the low-tension current to several thousand volts sufficient for a jump spark; and fourth, a distributor, to connect the high-tension current respectively with the several cylinders in the order of firing.

High-Tension Magnetos.

There are two types of magnetos commonly known as high-tension, but one of them only is, strictly speaking, a purely high-tension machine, combining within itself all four of the above mentioned parts. The other type contains within itself all of the parts except the high-tension coil or transformer, which, in this case, is placed in a separate mahogany box or hard fiber tube and mounted as near the magneto as convenient. A low-tension current is generated in the armature and sent across the timer or breaker points, where it is cut up into properly timed impulses of current. These low-tension impulses are sent into the primary winding of the separate transformer coil, where they are changed to high-tension in the secondary winding and sent back

through a heavily insulated wire to the distributor of the magneto, where they are sent again through heavily insulated wires to the respective cylinders.

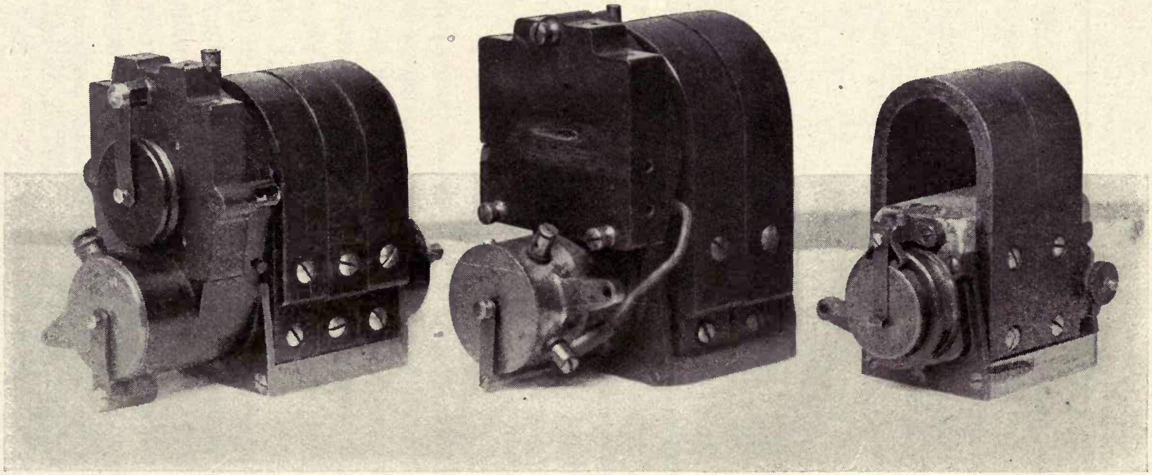
It is possible, in this system—but *not* in the pure high-tension machine—to substitute the current from a battery for that produced by the armature, when, of course, a good spark is produced, no matter how slowly the machine is turned over. This should be spoken of as a Dual system, and is highly satisfactory and very popular, but should not be confused with pure high-tension machines.

Theory of the Pure High-Tension Magneto.

Permanent magnets are always used to furnish the field magnetism in high-tension magnetos. A common two-pole or "H" armature is commonly used,[1] the central core of which consists of a number of soft iron stampings. As we already know, an armature of this type produces two impulses of current in a revolution—one positive and one negative.

In a previous chapter it was shown that, other things being equal, the voltage produced by an armature increases directly with the number of turns of wire in its winding. Why not, then, wind an armature with a sufficient number of turns of fine wire to produce a high-tension current, capable of jumping the spark gap at the plug? This has been tried, but, owing to the small space available for winding, it is impossible to get on anywhere near the required number of turns; in fact, only a few hundred volts can be reached. We also remember that a high voltage is needed only to *start* an arc, and only a few volts are necessary to

[1] There are a few special types of high tension magnetos employing either a stationary winding and inductor, or a magnetic shield arrangement, which give four impulses of current in a revolution. In all other respects, however, the principles are the same. Such a machine would be good for a multiple-cylinder, two-cycle motor.



A few samples of pure high tension magnetos. The one on the right has the condenser placed in an aluminum box under the arch of the magnets.

maintain it. We must, therefore, provide some other means for obtaining a momentary impulse of high voltage, capable of starting the arc, which can then be maintained for a short time by the comparatively low voltage produced in the armature. As we have already learned, other things being equal, the voltage produced in an armature varies directly with the speed at which the magnetic lines are cut or made to reverse through the armature winding. As the armature revolves, the magnetic reversals do not take place instantaneously, but are more or less gradual, thus tending to lower the voltage, yet, at the same time, prolonging the current impulses.

Wind, on the armature, two or three layers of rather coarse wire—say No. 24—and call it the Primary; around it wind as many turns as possible of carefully insulated, fine wire—say No. 36 to No. 40—and call it the Secondary. Now, short-circuit the primary winding and rotate the armature. The magnetic lines of force begin to cut through the windings, producing a current in the primary which gradually increases until a position is reached where the maximum number of lines of force is being cut. This induced current in the primary tends to strengthen the magnetism in the armature core. When the current in the short-circuited primary is at its maximum, suddenly interrupt it by opening the circuit and an almost instantaneous collapse of part of the magnetic lines in the armature will follow. This very rapid change of magnetism through the secondary winding will induce in it a momentary impulse of several thousand volts, sufficient to start an arc between the points of the spark plug. The arc is then maintained for a short time by a current of lower voltage, produced in the secondary winding by the rotation of the armature. A condenser of small capacity is connected across the breaker points to

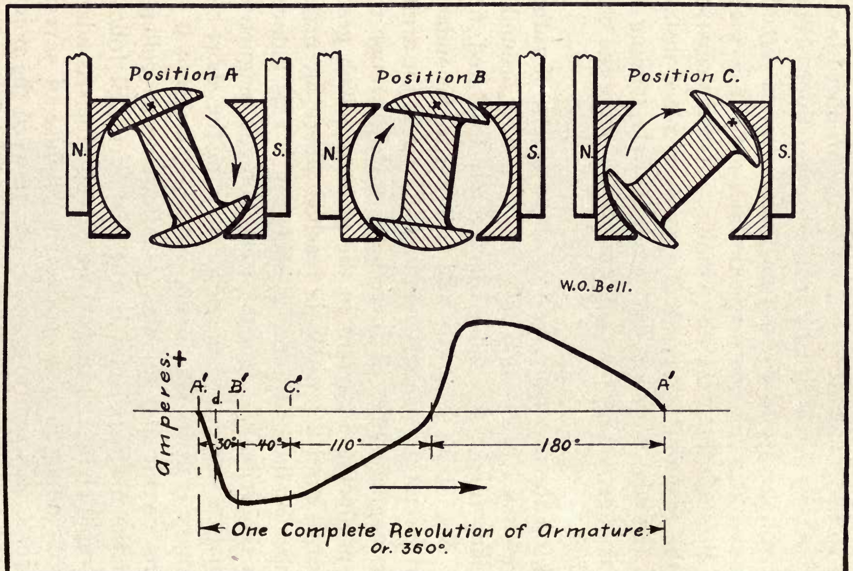


Fig. 1 shows three different positions of an "H" armature during rotation, and clearly illustrates how the magnetic lines are made to reverse their direction through the armature. The curve at the bottom of the figure is an oscillograph record of the current wave, showing the two impulses of current during one revolution—one positive and one negative.

prevent the platinum contacts from burning and to assist in the rapid collapse of the magnetic lines.

Fig. 1 shows three different positions of an "H" armature during rotation, and clearly illustrates how the magnetic lines are made to reverse their direction through the armature. The curve at the bottom of the figure is an oscillograph record of the current wave, showing the two impulses of current during one revolution—one positive and the other negative. The positions on the curve marked A′, B′ and C′ correspond to the three positions of the armature shown at A, B and C. A careful study of the relative positions will be of interest, as we can briefly mention only one or two of the most important points.

Suppose the cam to be set so as to open the primary circuit when the armature has reached the position indicated at "B" (Fig. 1). The wave is at its maximum height, so that the induced current in the Primary winding will be strongest. Also notice that, as the armature continues to rotate from position "B" to "C," the curve does not rapidly descend. The armature, therefore, cuts the lines of force at almost a uniform rate during that period, and, consequently, the current produced thereby in the secondary winding, will maintain a strong arc for a short time. Again, suppose the cam to be set so as to open the primary circuit when the armature has reached position "C"; the curve has begun to descend, and, consequently the arc will not jump as far or be as strong as in the first case. Position "B" corresponds to extreme advance, and "C" extreme retard, of a high-tension magneto having a spark advance range of 40 degrees. This explains why the spark is stronger when the magneto is advanced than when retarded, particularly at low engine speeds.

If the cam should be a trifle too far advanced so as to open the primary circuit *before* the armature reaches the position shown at "B," say at "d" (indicated on the curve), it is evident that the spark will be very weak and will not

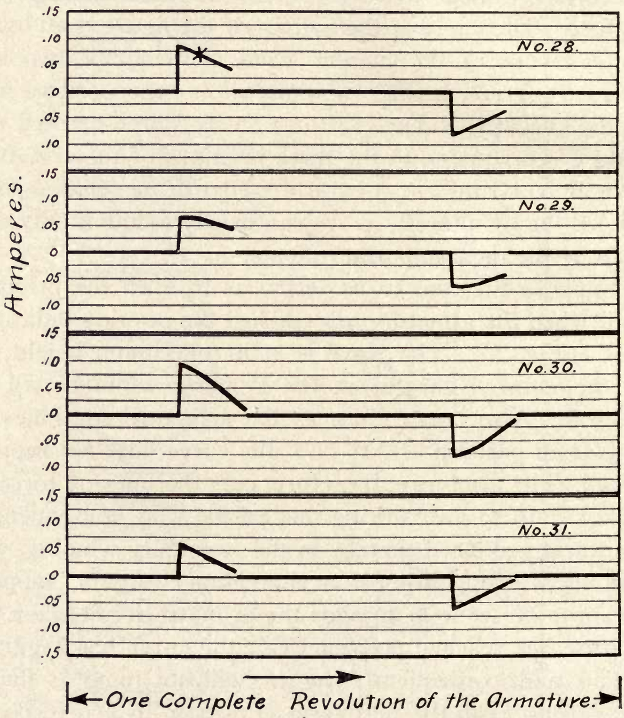


Fig. 2

A series of oscillograph records of the current forming the arc between the points of a spark plug. The first two are taken from the same magneto—No. 28 at extreme retard and No. 29 at extreme advance. Note that the arc does not immediately begin to die out on the advance position as it does on the retard

always jump between the points of the plug, causing the engine to miss fire. If the cam or facing against which it rubs, or the platinum points should be badly worn, or the platinum tipped contact screw backed out farther than it should be, the effect is the same as if the cam were advanced too far, and a short, weak spark will be the result. To avoid this trouble and to allow for a slight variation in manufacture, it is best to set the cam so as to open the circuit at a point well up on the curve, in order that a slight advance, due to wear or improper adjustment of the platinum points, will not weaken the spark.

Fig. 2 is a series of oscillograph records of the current forming the arc between the points of a spark plug. The first two are taken from the same magneto—No. 28 at extreme retard and No. 29 at extreme advance. Note that the arc does not immediately begin to die out on the advance position, as it does on the retard. No. 30 is from a different make of pure high-tension magneto and No. 31 is from a special form of Dual magneto, employing a separate high-tension winding in the form of a transformer, so designed with sufficient magnetic lag, etc., as to prolong the arc practically the same as a pure high-tension machine. There is no object in maintaining the arc too long; in fact it simply tends to burn up the points of the spark plug. The charge is, most likely, thoroughly ignited before the position marked "X" on curve No. 28, is reached.

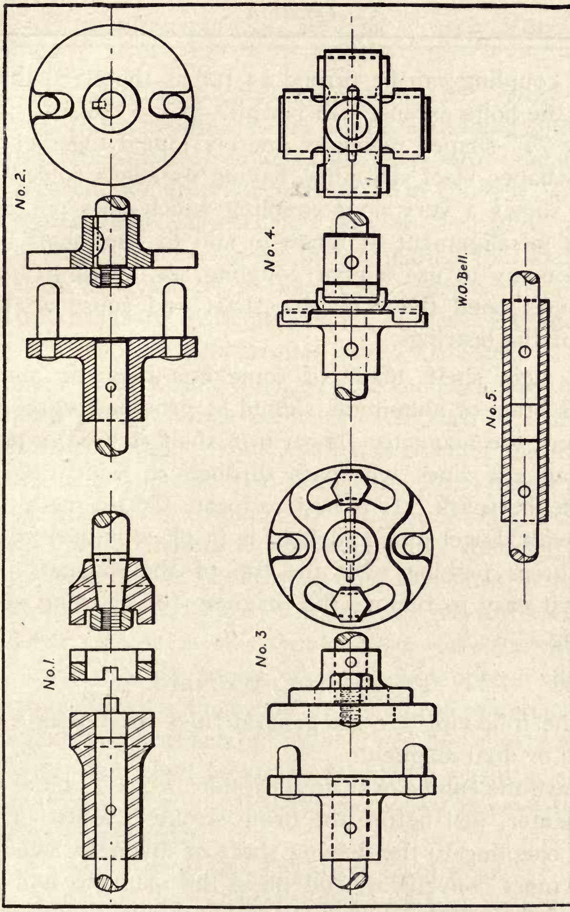
Chapter Thirteen

The Installation and Care of High-Tension Magnetos

All high-tension magnetos must be positively driven. They cannot, under any condition, be driven by belt or friction. Since the spark occurs only when the armature is in a certain position, the magneto must be so timed that the spark will occur at the instant ignition is required. The magneto is usually connected with some form of universal joint, directly to one end of the cam or pump shaft, or a special short shaft extending from one of the cam shaft gears that runs at the proper speed. The following table shows the different speeds at which magnetos should be driven relative to the speed of the motor:

Number of cylinders.	Cycle.	Speed.	Form of cam.
4	4	Crank shaft	Double
2	4	Crank shaft	Single
3	4	1½ x crank shaft	Single
6	4	1½ x crank shaft	Double
4	2	2 x crank shaft	Double
2	2	2 x crank shaft	Single
3	2	1½ x crank shaft	Double
6	2	3 x crank shaft	Double

Fig. 6 shows several forms of couplings. No. 1 is the popular Oldham universal coupling; No. 2 is a fairly satisfactory device, consisting of two pins in one end of the coupling, working in two corresponding slots in the other end. No. 3 shows a device for slightly changing the timing after both ends of the coupling are secured to the shafts. When the two hexagon bolts are loosened, the magneto end



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of the coupling can be turned as far as the slots, through which the bolts extend, will permit. No. 4 consists of two similar "T"-shaped members, loosely joined together, with a star-shaped steel stamping, having its edges folded over. No. 5 shows a very poor coupling which does not permit of any misalignment of magneto and driving shaft. It is not economy to use a poor coupling, as it will strain and sometimes bend the armature shaft and cause an undue wear of the bearings.

A rigid shelf, made of some non-magnetic material, such as brass or aluminum, should be provided, upon which to mount the magneto. If an iron shelf is used, a part of the magnetic lines will pass through it, which tends to weaken the spark. It is best to locate the magneto on the shelf with dowel pins and hold it in place with a strap of sheet brass passing over the top of the magnets. This makes it easy to remove the magneto for cleaning and inspecting.

Timing the Magneto.

The following are the general rules for timing a high-tension or dual magneto.

Turn the engine over until cylinder No. 1 is on the upper dead center, just before the firing stroke. Secure one end of the coupling to the driving shaft or magneto, whichever is the most convenient, and place the magneto and other parts of the coupling in position. Turn the spark advance lever to the position of extreme retard, which will be in the same direction as the armature runs. Remove the cover of the interrupter or breaker box, so that the contact points can be seen, and slowly turn the armature in *the direction it is to run* until the contact points just begin to separate.

This point should be carefully determined. Now secure both ends of the coupling to the shafts with taper pins. Remove the front plate or cover of the distributor and see with what segment the distributor hand is in contact. Connect this segment with high-tension wire to the spark plug of cylinder No. 1, then connect the remaining terminals with the rest of the cylinders in the proper order of firing, bearing in mind that the distributor hand, in most cases, revolves in the *opposite direction* to that of the armature.

There is usually a binding post on pure high-tension machines, which, when connected through a switch to ground on the engine frame, will short-circuit the primary winding, thereby shutting off the spark. Dual magneto connections are more complicated and the wiring diagrams furnished by the makers should be carefully followed. Care must be exercised in connecting dual magnetos, not to get the battery connected directly across the armature winding, even for a second, as this would make an electro-magnet out of the armature which, likely, would oppose the field magnets and weaken them. It is convenient sometimes with dual magnetos to connect an electric bell and dry battery in series with the contact points, to determine when the separation occurs. Unfortunately, this cannot be done with pure high-tension machines.

Care of High-Tension Magnetos.

A few hints regarding the care of high-tension magnetos may be helpful. It is often a very good thing to cover the machine with a rubber or leather hood, made especially for the purpose, since dust, dirt, grease and particularly water, are all enemies of the magneto. The glass or porcelain knob, which covers the safety spark gap (if there is one), should be kept clean and free from grease and dirt.

The distributor should be kept clean and dry and the path, over which the carbon distributing brush slides, ought to be wiped off occasionally with a clean cloth, moistened with gasoline, for a slight carbon deposit will, in time, form between the segments and cause misfiring. The spiral spring behind the carbon distributing brush must not be too stiff; it should be just stiff enough to hold the brush in very light contact with the surface over which it slides.

Fig. 3 is a diagrammatic view of a pure high-tension magneto and shows the connections and relations of the several parts. At the left is a sectional view of the heavily insulated collecting ring for leading the high-tension current from the secondary winding on the armature, to the distributing hand, from which it is sent to the different cylinders. When tracing out the connections, note that one end each of the primary and secondary windings is grounded to the armature core. A safety spark gap is provided, over which the spark can find an easy path, should a wire come off of a spark plug, thereby preventing unnecessary and dangerous strain on the insulation of the secondary winding.

Fig. 4 is a sectional drawing of a special form of dual magneto, which has the high-tension winding made in the form of a transformer and placed under the arch of the magnets. In this machine as in all dual magnetos, the armature has just one primary winding of coarse wire.

A high-tension magneto is not an easy piece of apparatus to manufacture. The greatest care, both mechanically and electrically, must be exercised throughout the entire construction.

The Magnetic Circuit.

The magnets should be carefully made of the best magnet steel and strongly magnetized and seasoned before plac-

ing on the machine. In order to make the magnetic circuit as good as possible, the inside surfaces of the magnets should be ground bright and smooth *after* hardening, but *before* magnetizing, and the pole pieces smoothed and all

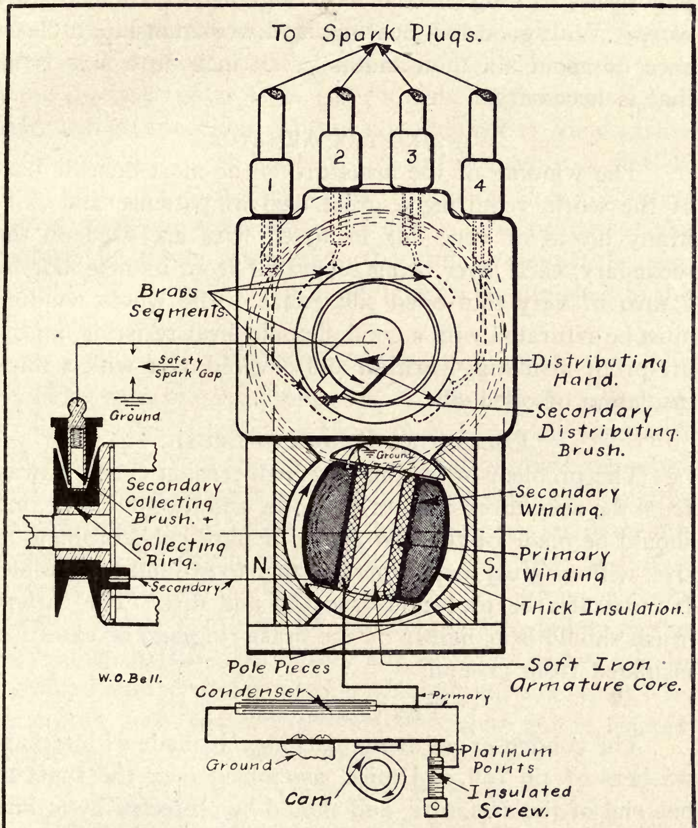


Fig. 3, a diagrammatic view of a pure high-tension magneto, which clearly shows the connections and relations of the several parts. At the left is a sectional view of the heavily insulated collecting ring for leading the high-tension current from the secondary winding on the armature, to the distributing hand, from which it is sent to the different cylinders.

scale removed so as to make a perfect fit with the magnets. The armature should be made with only a few thousandths of an inch clearance, but must not be close enough to the pole pieces to drag after the bearings have become slightly worn. With good ball bearings and workmanship, a clearance of about six thousandths of an inch on a side is all that is necessary.

Winding the Armature.

The winding of the armature is the most delicate part of the work, requiring a great deal of patience and skill. Many layers of very fine insulated wire are used on the secondary, each layer being separated from its neighbor by a turn of very thin oiled silk gauze. The whole winding must be saturated with a good, flexible, heat-resisting, moisture-proof insulating varnish, and covered over with a thick insulation of oiled silk.

Collecting Ring and Brush.

The problem of leading the high-tension current away from the armature is not an easy one, and the collecting ring should be made of the best grade of hard rubber, ample in size, with as great a sparking distance to ground as possible. It must also be protected from oil and dirt. The carbon brush should bear lightly on the brass ring and be carefully insulated from ground.

The Condenser.

The condenser, in many machines, is made of alternate washers of tin foil and mica, assembled over the shaft at one end of the armature, and should be protected by a thin, brass case. In other machines it consists of alternate sheets of tin foil and mica, assembled in a brass or aluminum case, placed under the arch of the magnets.

The Interrupter.

The interrupter or breaker assumes many different forms, but the principle in all cases is the same. In many pure high-tension machines, it is made to rotate with the armature and two stationary fiber pieces act as cams to effect a separation of the platinum points. The main thing about an interrupter is to have it light and responsive, so that, at high speeds, it will not miss contact as some earlier forms are apt to do. There are, unfortunately, a few of these still on the market. Dual magnetos have the interrupter mounted stationary and effect a separation of the contacts by a cam attached to the armature shaft, bearing against a steel roller, or steel or fiber facing attached to the interrupter arm.

Safety Spark Gap.

The wire or spring clip, which connects the collecting brush with the distributing hand, must be widely separated and insulated from the ground or metal parts of the magneto. The safety spark gap is often placed under this strip and protected from dirt and water by a glass or porcelain insulator. The gap is usually about $\frac{5}{16}$ inch long, and, if it is wet or dirty, or too short, the spark will jump or creep across it rather than take the gap between the points of the spark plug, particularly if they happen to be rather widely separated, and irregular missing of explosion will result. In some pure high-tension machines, the safety gap is located on one end of the armature near the winding.

High-Tension Distributor.

There are two general forms of distributor, the passing contact, where the spark is made to jump a small air gap between the distributing hand and brass segments; and the

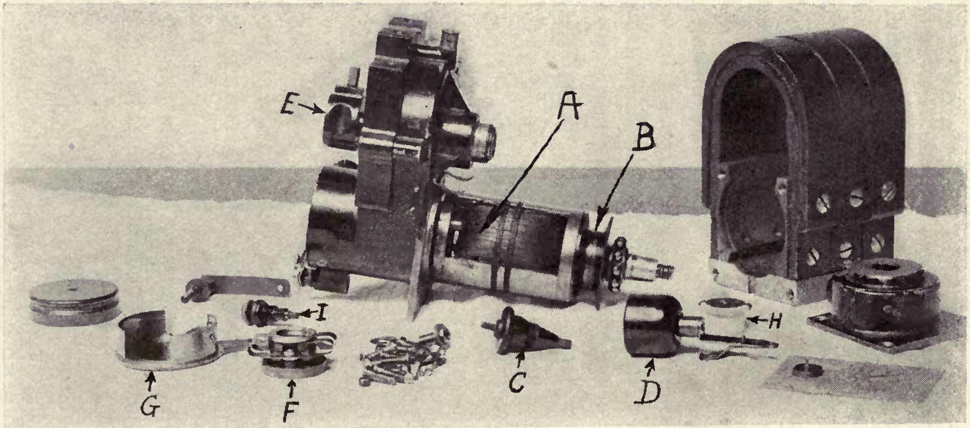


Fig. 5. A pure high-tension magneto partly disassembled. A warning to the novice not to take his magneto apart.

rubbing contact, where a carbon brush is made to slide from one brass segment to the next. The passing contact is cheaper to manufacture than the other, but is not considered as good because some energy is lost in forcing the spark across the air gap. If this gap could be kept less than 1-64 inch at all times, this objection would be overcome, but it is impracticable, for mechanical reasons, to do so. It is well to mold the brass segments into a block of special hard rubber and then smooth up in a lathe the surface against which the carbon brush rubs. The distributing hand must be driven by gears from the armature shaft at such a speed that it will be in contact with a brass segment at the instant the interrupter points are separated.

Fig. 5 is a photograph of a pure high-tension magneto partly disassembled. *A* is the high-tension winding on the armature; *B* the collecting ring; *C* the carbon collecting brush and hard rubber holder; *D* the hard rubber protector and brush that leads the high-tension current into the distributing hand; *E* the distributing hand and carbon brush; *F* the special form of interrupter that rotates with the armature; *G* the spark advance lever, showing the stationary fiber cams; *H* the porcelain safety spark gap protector, and *I* the small carbon brush which leads the primary current to the switch for grounding to stop the magneto. The condenser is mounted on the left hand end of the armature and does not show.

The contact points should not separate more than the thickness of an ordinary, rather thin business card, and should they become badly pitted, they must be made smooth with a very fine file or replaced with new ones.

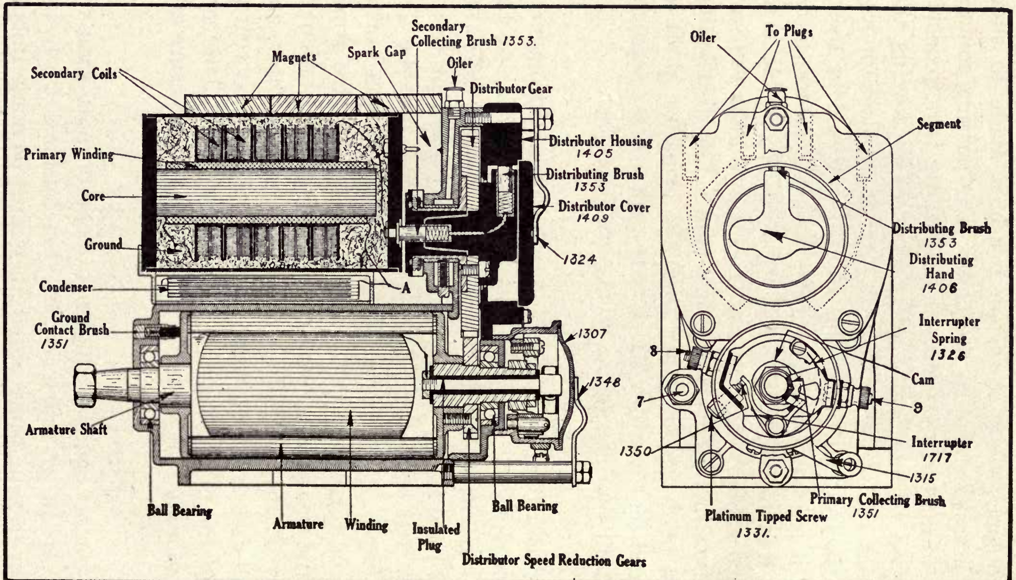


Fig. 4—A sectional drawing of a special form of dual magneto, which has the high-tension winding made in the form of a transformer and placed under the arch of the magnets. In this case, as in all dual magnetos, the armature has just one primary winding of coarse wire.

Most magnetos are provided with three or more oil holes, which should receive a few drops of high grade thin oil several times a season, according to how much the machine is used. It is not well nor necessary to flood the machine with oil, neither should it be run dry. The ball bearings are packed with hard grease before the machines leave the factory, and so very little oiling is necessary for the first few months' use.

There is nothing difficult about caring for a magneto. If these few simple things are systematically looked after, trouble with the magneto is not likely to develop.

Chapter Fourteen

Low-Tension Positively Driven Make-and-Break Magnetos for Stationary Engines

The newest type of ignition receiving the attention of progressive manufacturers of stationary farm engines, is a gear-driven magneto, the armature of which is designed to act as a make and break coil as well as to perform its regular function of generating the current. With this type of magneto the make-and-break coil and batteries are entirely eliminated and the magneto made a permanent part of the engine, thereby making the system extremely simple.

Operation of System.

A two-pole or "H" armature is made to revolve between the poles of a permanent magnet. The armature has a single winding, one end of which is grounded to the armature core. The other end is brought out to a collecting ring against which bears a collecting brush. This brush is connected to the insulated point of the igniter on the engine. The armature is positively driven from the crank or cam shaft so that the current impulses will be at their maximum strength the instant ignition is required. When the armature starts to revolve a current is produced in its winding,

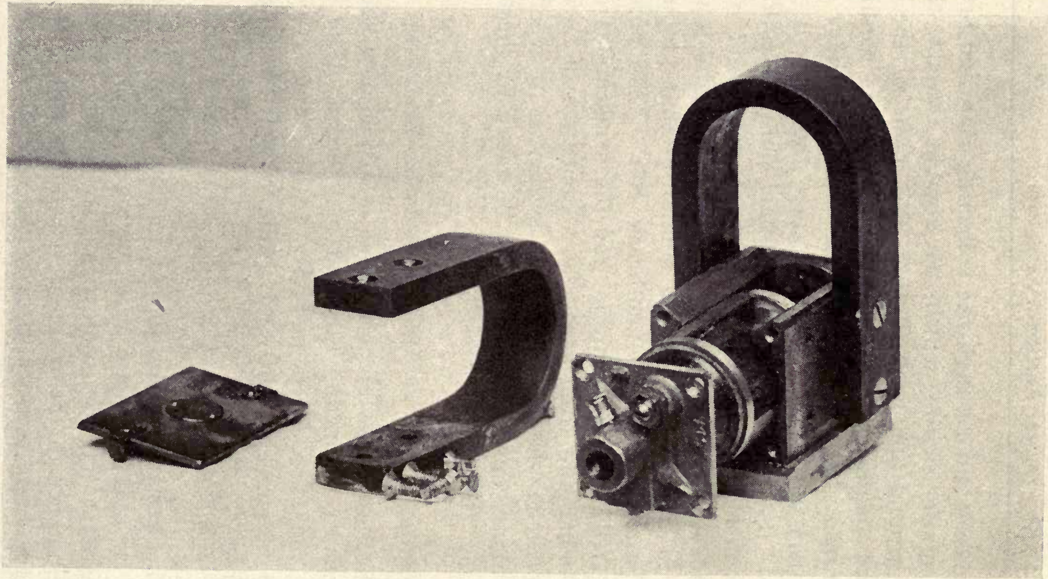
which passes out through the collecting ring and brush to the igniter points, which are now in contact, then to the ground and back through the frame of the engine and magneto to the grounded end of the winding. The current begins to build up and strengthens the magnetism in the armature. When the current has reached its maximum the igniter points separate, after which the armature acts as a make-and-break coil and delivers the energy stored in it to the igniter points in the form of an arc similar to that produced by a battery and make-and-break coil. This process is repeated for every ignition, and the armature is constantly changing from acting as a generator of current to a make-and-break coil. This system as a whole is very simple, but great care must be taken in properly designing all of the parts.

Construction of Magneto.—Field Magnets.

The best grade of permanent steel magnets should be used for furnishing the field magnetism. The pole pieces must be fitted perfectly to the magnets and should be made of the best grade of soft "magnetic" cast iron.

Armature.

The armature core should be cast from a special grade of soft magnetic iron having a high magnetic permeability at low densities. In order to reduce the reluctance of the magnetic circuit as much as possible, the cross sectional area of the core must be made large enough to easily carry all the magnetic lines



Make-and-break magneto partly taken apart. Notice the grounding brush at rear end of machine and the collecting ring at the front end.

from one pole piece to the other, and the clearance between the pole pieces and armature should not exceed eight thousandths of an inch. On the other hand, the armature must not run close enough to the pole pieces to rub should the bearings become slightly worn.

The armature has a single winding of silk insulated wire, varying with different makes of machines from No. 22 to No. 32 B. & S. gage. One end of the winding is grounded by soldering to the armature core, and the other end is connected to the insulated collecting ring.

Grounding Brush.

The current is led away from the machine by the collecting ring and brush, and the return circuit passes through the engine frame into the frame of the magneto and back to the grounded end of the armature winding. The bearings, however, must not be depended upon for carrying the current to the armature winding. The film of oil which surrounds the shaft acts as a high resistance and prevents a steady flow of current. If the current is forced across this film of oil a sort of electrolysis of the steel shaft will take place, which will not only destroy the oil but will roughen the shaft and bearing.

There are various forms of grounding brushes such as plain copper gauze brushes, gauze brushes saturated with graphite, and carbon brushes. These brushes are usually round and are made to bear against the bronze end of the armature cap. The graphite saturated copper gauze brush is very satisfactory.

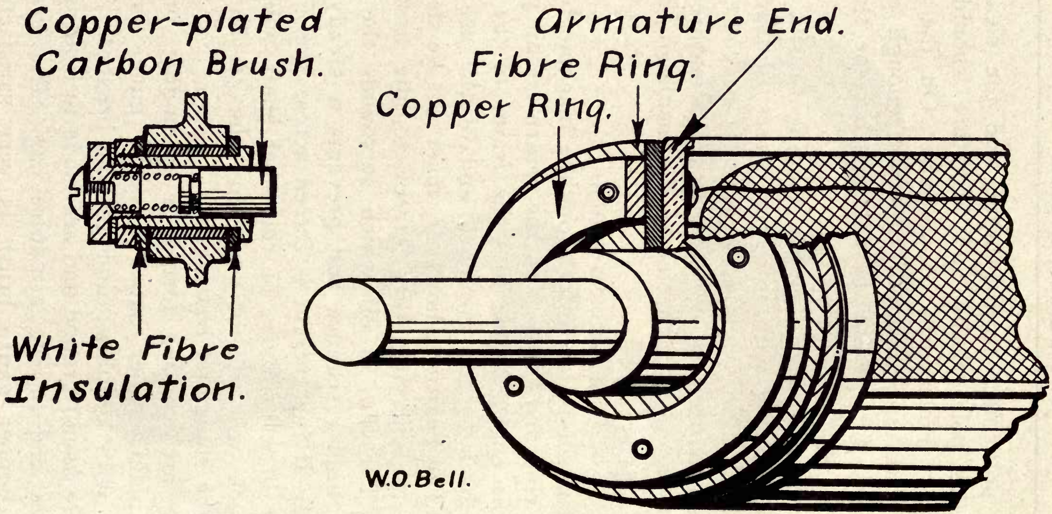


Fig. 1
Showing the construction and insulation of the copper collecting ring and brush holder.

Collecting Ring and Brush.

It is not easy to design a collecting ring and brush that will operate continuously without any attention. There are several different methods which have been used with more or less satisfaction.

In some machines one end of the armature shaft has a hole bored lengthwise through it, in which is placed an insulated copper or steel rod, the outer end of which terminates in a copper button or better, a steel disc. If steel is used, it should be highly polished and glass hard. A gauze or carbon brush is arranged to bear against the center of the steel button. It is better, however, to place two smaller brushes near the outside edge of the steel disc, so that the wear on the brushes will be more uniform and the surface will be kept cleaner than if one larger brush were used against the center of the disc. In some constructions the steel disc is replaced with a short length of steel shaft and one or two brushes made to bear on the side of this shaft. This is not as satisfactory, however.

Good electrical contact between the brush and the surface over which it slides is necessary, because if the brush starts sparking it will rapidly wear, and the sparking action will roughen the surface and cause imperfect contact. A very satisfactory arrangement is a special carbon brush about 5/16 of an inch in diameter bearing lightly against the surface of a flat ring made of hard commutator copper. Brass or steel is in no way as good as this particular form of

copper. The carbon brush can be greatly improved by having it made with a little graphite which acts as a lubricant, thereby reducing friction and wear. It should also be heavily copper plated to reduce the electrical resistance. The copper ring must be carefully insulated from ground. Washers of hard white fiber, 1/16 of an inch thick are good for this purpose. Figure 1 is a drawing showing the detailed construction of the collecting ring and brush holder. The brush holder must also be well insulated and firmly fastened so as not to work loose. It is very important that the brush make a good electrical contact with its holder, and at the same time be free to slide in and out so that a light spiral spring will be sufficient to hold it firmly against the copper ring.

Bearings.

Needless to say the bearings should be provided with an oil chamber of ample capacity so that frequent attention will not be necessary. In order to protect the armature from dust and moisture a tight fitting cover over the housing should be provided. This also will prevent iron filings from being drawn in between the pole pieces by the magnetic attraction. A felt washer fitted snugly over the shaft between the bearing and the collecting ring will help materially in keeping oil away from the armature and brush.

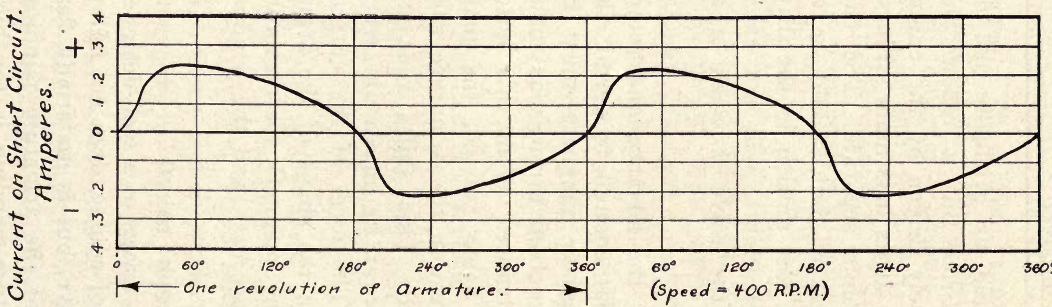
Current Waves.

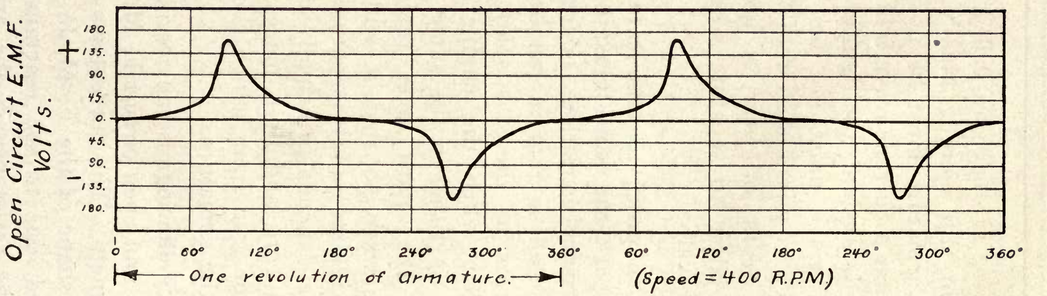
The armature does not give a steady flow of current like a battery or dynamo, but gives two separate impulses of current every revolution—one positive and one negative. These impulses or current

waves, as they are called, build up gradually and die down still more gradually. From this it follows that the armature must be positively driven by the engine so that a current wave will be at its maximum strength at the instant the igniter points separate. The current wave must not be "peaked" but should be as "flat" as possible so that any lost motion in the driving gears, or wear of igniter points, will not cause the latter to separate when the wave is weak or at zero value.

In order to take care of the advance and retard of spark the wave must be flat enough to permit the necessary variation, or the whole magneto must be mounted so that it can be revolved through as many degrees as there is spark advance. With this latter system when the engine is being started, the magneto is tilted in the same direction the armature runs and the spark lever retarded. This shifts the current wave so that it will be at its maximum when the igniter points separate. The form of the current wave depends principally upon the shape of the armature core and pole pieces, the magnetic permeability of the iron from which they are cast, and the winding on the armature.

Following is an oscillograph record of the current and open circuit E. M. F. waves of a well-designed magneto. The current wave, of course, does not follow the shape of the E. M. F. wave, but is materially flattened, due to the reactance of the armature winding. If the resistance of the armature winding is too high





Oscillograph record, showing the E. M. F. wave on open circuit and current wave on closed circuit, of a well designed make-and-break magneto.

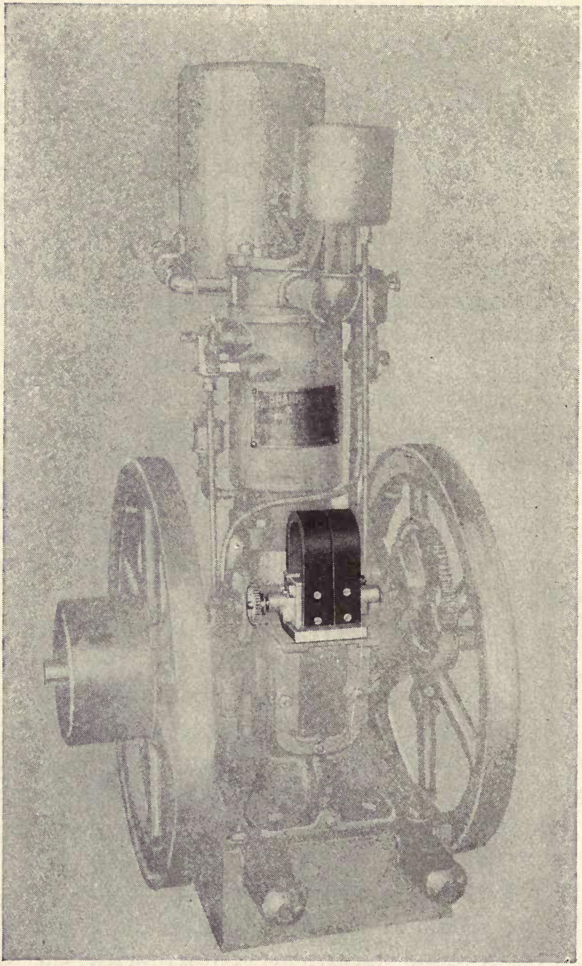
the current will be choked and will not respond as rapidly as it should. On the other hand, if it is too low the current will not persist long enough, thereby shortening the duration of the arc. The amperage will also be increased, which will more rapidly destroy the igniter points. The current wave on this magneto is strong enough to produce a good spark during about 40 degrees of revolution. This is ample to permit a considerable variation of adjustment between the armature and igniter points.

Timing the Magneto.

Any good coupling such as is used for high tension magnetos, or a set of gears, can be used to drive the magneto. There is usually a mark placed on the magneto armature, by the manufacturer, to show the position it is in when the current wave is at its maximum strength. This occurs at the instant the edge of the armature core has pulled away from the edge of the pole piece about 1-16 of an inch.

The timing is very simple. Turn the engine over slowly until the igniter points just snap apart; then turn the magneto in the direction it is to run until the armature has pulled away from the pole piece 1-16 of an inch, or as shown by the marks on the armature. Now secure the magneto in place and connect a wire from the collecting brush to the igniter. The magneto can be run in either direction.

If the magneto is not mounted on a metal base which is in good electrical contact with the engine frame, it will be necessary to ground it by connecting a wire from the body of the magneto to the frame



A typical installation—the magneto is gear driven at engine speed from the cam shaft.

of the engine. The shut-off switch can be put in series with the wire leading to the igniter, or it can be arranged to ground the magneto by short circuiting the armature, thereby cutting off ignition.

Relation of Engine and Magneto Speeds.

It is not necessary to use every current wave that is produced. A four-cycle single cylinder engine calls for one spark every other revolution of the crank shaft; therefore, if the magneto is run at engine speed, only one out of every four current waves will be used. A single cylinder two cycle, and a two cylinder four cycle engine will use every other wave; a four cylinder, four cycle engine, which requires two sparks every revolution, will use every impulse. It is often necessary with low speed engines to run the magneto twice engine speed in order to increase its efficiency and make starting on the magneto easier. This, of course, doubles the number of current waves, which is immaterial, but also reduces by one-half the available spark advance. A magneto giving a current wave strong enough to ignite the charge during 60 degrees of armature revolution, will allow the same number of degrees spark advance on the crank shaft if run at engine speed, and only half as much or 30 degrees if driven twice engine speed.

Multiple Cylinder Engines.

This type of magneto will give good results on engines of more than one cylinder provided it is correctly timed. The igniters on the different cylin-

ders are all connected to a common wire leading to the collecting brush on the magneto. The two principal things to observe are: First, the magneto must be driven at such a speed that a current wave will be at its maximum every time any of the igniter points separate; second, the igniters must be so arranged that at the instant any one of them snaps—causing ignition—all the others will be out of contact. It is easy to see that if any of the other igniters are in contact when ignition is required in cylinder No. 1, the current will flow across them rather than produce an arc in the first cylinder.

It is often a good plan with single cylinder engines to run the magneto at 1¼ engine speed. This makes use of some positive and some negative waves, causing the current to reverse its direction across the igniter points every time they separate. Under these conditions "pitting" of one point and "building up" on the other is impossible and the wear is uniform.

Wear of Igniter Points.

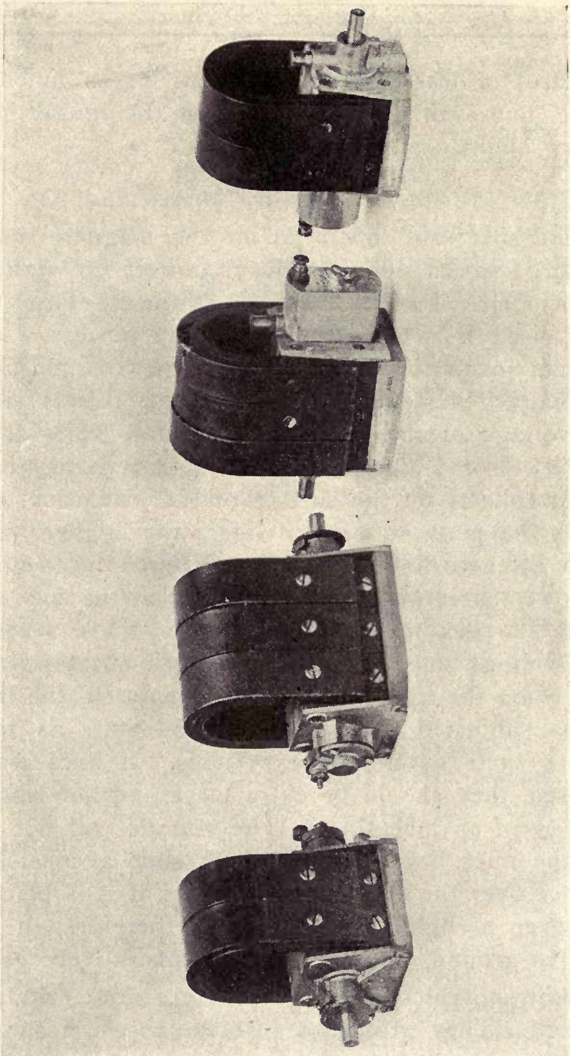
The igniter points will last considerably longer with this type of magneto than with battery systems. This is due, in part, to the fact that much less amperage passes across the arc when a magneto is used than with a battery and coil. The oscillograms on page 45 show that with battery systems from 1 to 4 amperes pass through the arc, while the maximum current possible with the magneto giving the current wave shown on page 124 is 0.25 of an ampere. The several different makes of magnetos, however, differ somewhat in this respect. Some machines having

armatures of less resistance give twice as much amperage, but even then the wear on the igniter points is very slight.

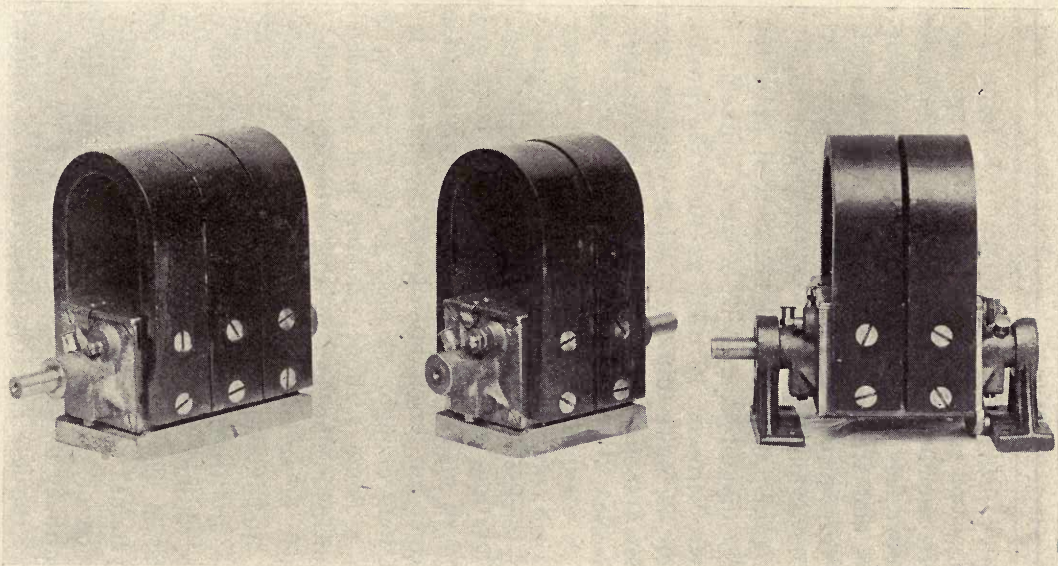
INSULATION OF IGNITER.

The successful operation of the magneto depends to a large extent upon the insulation of the stationary igniter point. Two or three times the insulation ordinarily used is necessary, particularly since a lack of sufficient insulation at this point is so common a fault with battery systems. The reason for this is simple: The voltage of the magneto is several times that of a set of 4 or 6 dry cells, and so if a greasy carbon deposit collects on the surface of the insulation, which usually happens sooner or later, the higher voltage of the magneto finds an easy path across it to ground. The lower curve on page 124 shows that the open circuit E. M. F. rises to about 150 volts. Since several of these voltage impulses occur between successive ignitions when the igniter points are separated, the insulation is subjected to a strain of 150 volts as against about 6 volts with battery systems. If mica washers are used, they should be extra large and not less than ¼ or ⅜ of an inch thick. The voltage will not puncture the mica but will "skate" or slide a considerable distance over the surface, particularly if it is blackened with even a slight carbon deposit; therefore, the "distance to ground" must be kept comparatively great.

Built up thick mica washers are not entirely satisfactory. They are quite sure to loosen in time and the heat and pressure of constant explosions will drive



A group of two and three magnet, make-and-break magnetos.



The magneto on the right is mounted on brackets and can be tilted to take care of a large range of spark advance.

grease and carbon in between them. A form of molded composition or so-called "lava" bushings are very good. If the bushings are thoroughly annealed, to make them less sensitive to sudden changes of temperature, and are correctly shaped and installed, they will be very durable and entirely satisfactory. A cone-shaped lava bushing, fitted in a ground taper joint in the igniter casting, will be so well protected mechanically that breakage will be very unlikely.

When kerosene is used as fuel, the problem of insulation is more difficult. Mica washers seem to break down sooner and are even less satisfactory than with gasoline.

Heat of Arc.

The temperature the arc attains is not as important as its duration, viz.: the actual time it lasts. Almost any kind of an electric spark is *hot* enough to ignite the charge, but often fails to do so because it does not last long enough. A piece of paper can be passed through a flame without catching fire, provided it is done quickly. The gas in the cylinder ignites very quickly, to be sure, but some kinds of sparks are even quicker, and ignition fails on that account.

The arc from this type of magneto is of ample duration to ignite the most stubborn mixture, in fact its duration is, as a rule, longer than that of battery systems. The applied voltage is higher, the inductance of the winding is greater, and the armature continues to generate current for a part of a second after the igniter points separate, all of which tends to prolong the arc.

Sizes of Magnetos.

Make-and-break magnetos of this type are made in two principal sizes, generally known as "Two Magnet" and "Three Magnet." The larger machine is a trifle longer than the smaller and has one more magnet. This extra magnetic strength and length of armature makes the three-magnet machine more efficient at very slow speeds. A good two-magnet magneto will give a spark strong enough to start the engine at 22 revolutions per minute, while the larger machine of same make will give as good a spark at 12 revolutions per minute. For engines up to 6 or 8 H. P. that can be easily turned over, the two-magnet magneto is satisfactory, but for starting larger engines the three-magnet machine should be used. Where starting is accomplished with a battery and cheap coil, and the magneto run not less than 500 revolutions per minute, the two-magnet machine will operate successfully on engines of 30 or more horsepower.

Oscillating Make-and-Break Magnetos.

There are a few special forms of magnetos arranged to be attached directly to the igniter plate. The armature is fastened to the movable igniter point so that it will oscillate across the magnetic field. Synchronism between the armature and igniter is absolute since they are both operated by the same tripping mechanism. The tendency in designing this type of magneto, so far, has been to make it too small and the magnetic circuit of too high reluctance, resulting in a lack of reserve spark strength to meet adverse

conditions, and in the magnets losing their strength after being in service a few months. This type is still in the experimental stage, but the idea of making the magneto a part of the igniter itself is correct, and the practical difficulties attending its achievement will, without doubt, soon be overcome.

Since reliable ignition apparatus can be had today, which was not so a few years ago, the far greater part of present-day ignition trouble is due to no other cause than the tinkering and guessing of the man who DOESN'T KNOW.

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